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GE-MTSD-R-057

PYROTECHNIC HAZARDS CLASSIFICATION AND EVALUATION PROGRAM

ELECTROSTATIC VULNERABILITY OF THE E8 AND XM15/XM165 CLUSTERS PHASE II FINAL REPORT MARCH 12, 1971

PREPARED FOR
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MISSISSIPPI TEST FACILITY

(NASA-CR-123040) PYROTECHNIC HAZARDS CLASSIFICATION AND EVALUATION PROGRAM. ELECTROSTATIC VULNERABILITY OF THE E8 AND XM15/XM165 CLUSTERS, PHASE (General Electric Co.) 12 Mar. 1971 188 p CSCL 19A G3/33
N72-18970
Unclas
20011
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM

GENERAL ELECTRIC

GE-MTSD-R-057

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AND

EVALUATION PROGRAM

ELECTROSTATIC VULNERABILITY OF THE E8 AND XM15/XM165 CLUSTERS

PHASE II FINAL REPORT

MARCH 12, 1971

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FOREWORD

This report contains the results of Phase II of a two-phase investigation of the electrostatic vulnerability of the E8 and XM15/XM165 clusters being conducted by the General Electric Company, Technical and Operations Services Department (GE-TOSD) for the Smoke and Riot Control Branch, Production and Engineering Laboratory (administered through the Engineering Test and Evaluation Section, Process Technology Branch, Chemical Process Laboratory), Weapons Development and Engineering Laboratory, Edgewood Arsenal, Edgewood, Maryland. The contracting agency is the National Aeronautics and Space Administration (NASA), George C. Marshall Space Flight Center, Huntsville, Alabama. This program is being conducted at the NASA Mississippi Test Facility, Bay St. Louis, Mississippi, under contract NAS8-23524.

Phase I consisted of identification of the characteristics of the E8 and XM15/XM165 systems which affect their electrostatic vulnerability and a survey of the manufacturers' facilities. The Phase I final report was issued as Report Number GE-MTSD-R-052, dated December 31, 1970. In many respects it serves as an introduction to Phase II. Its content includes the rationale for conduct of the study, the technical approach, description of the E8 and XM15/XM165 systems, and a discussion of electrostatic theory.

The content of the Phase II program was originally developed in the Phase I report. In certain instances priorities were established and tests were added to or deleted from the test plan as requested by Edgewood Arsenal personnel. These modifications are not described herein but are reflected by the report content.

The Phase II report is structured around the phenomena being tested or parameters being measured. Even though two distinct systems (E8 and XM15/XM165) are being evaluated, the test approach and procedures are very similar.

In order to expedite dissemination of test results, segments of this report were previously distributed as GE-MTSD-R-041, "Test Report, Electrostatic Sensitivity of the XM15 Fuse Train"; GE-MTSD-R-047, "Investigation Report, Inadvertent Functioning of an XM15 Cluster During Manufacturing"; GE-MTSD-R-048, "Preliminary Report on Spark Sensitivity Test of Subsystems Configurations of the XM15 Fuse Train Encapsulated in RTV-60"; and various letter reports with limited distribution.

ACKNOWLEDGEMENTS

Edgewood Arsenal personnel who have generously contributed to the success of this program are:

- W. P. Junkin, Chief, Chemical Process Laboratory
- J. K. Bartell, Chief, Process Technology Branch
- W. P. Henderson, Supervisor, Engineering Test and Evaluation Section
- A. Bruce, Chief, Smoke and Riot Control Branch
- Sam Hasson, Project Engineer, XM15/XM165
- Henry M. Drupieski, Project Engineer, E8
- A. Becher, Chief, Safety
- John Kerr, Safety Engineer
- Paul Swindell, Safety Engineer

Grateful acknowledgement is made to John H. Ivey, Technical Representative, Edgewood Programs, National Aeronautics and Space Administration, Mississippi Test Facility, for his cooperation and support.

Sincere thanks are extended to Dr. A. T. Tweedie, Material Testing Laboratory, Space Systems, Space Division, and Dr. D. A. Vermilyea, Surfaces and Reactions Branch, Physical Chemistry Laboratory, Research and Development, General Electric Company, for their consultant services.

Sincere appreciation is extended to the following Signal Systems, Electronic Systems Laboratory, Electronics Laboratory, General Electric Company personnel for their cooperation, support, and significant contribution:

- Clayton R. Roberts, Senior Project Engineer
- Paul H. Kirchner, Mathematician and Engineer
- Dr. L. C. Humphrey, Senior Physicist

The following Materiel Testing and Research, Technical Projects Operation, Technical and Operations Services Department, General Electric personnel contributed significantly:

- P. V. King, Manager, Materiel Testing and Research
- Dr. T. M. Small, Project Engineer
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- J. C. Boatner, Electrical Engineer
- J. E. Templet, Supervisor, Electronic Calibration and Repair
- R. I. Cedar-Brown, Consulting Engineer, Systems Design
- C. E. McGee, Project Engineer, E8 and XM15/XM165 Project
- D. M. Koger, Manager, Pyrotechnic Hazards Classification and Evaluation (KEMOPS) Program
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ABSTRACT

This report describes the results of investigations conducted by the Materiel Testing and Research Subsection (MT&R), Technical and Operations Services Department, Space Division, of the General Electric Company in conjunction with the Smoke and Riot Control Branch, Production and Maintenance Engineering Laboratory, and Engineering Test and Evaluation Section, Process Technology Branch, Chemical Process Laboratory, Weapons Development and Engineering Laboratory, Edgewood Arsenal, Edgewood, Maryland. This two-phase investigation is concerned mainly with electrostatic phenomena. Phase I consisted of electrostatic vulnerability identification and the survey of manufacturers' facilities; and Phase II consisted of implementing the test plan developed in the Phase I final report, Section 7, and performing related tasks as specified by Edgewood Arsenal personnel.

The testing includes measurement of the severity of the primary charge generation mechanism, triboelectric effects between dissimilar surfaces; refinement of equivalent circuits of the XM15/XM165 and E8 fuse trains; evaluation of the electrostatic spark discharge characteristics predicted by an equivalent circuit analysis; and determination of the spark ignition sensitivity of materials, components, junctions, and subassemblies which compose the XM15/XM165 and E8 units.

Special studies were also performed. These special tests included ignition sensitivity of the complete XM15 fuse train when subjected to discharges through its entire length, measurement of electrostatic potentials which occur during the E8 foaming operation during fabrication, and investigation of the inadvertent functioning of an XM15 cluster during manufacturing.

The test results are discussed and related to the effectiveness of suggested modification to reduce the electrostatic ignition sensitivity. This analysis contributed to the development of a Phase III study test plan, which is also included herein.

EXECUTIVE SUMMARY

The inadverent functioning of several CS dispersing pyrotechnic rounds has focused attention on the possibility of electrostatic ignition as the causative factor. This report describes the results of the second phase of a proposed three-phase study of the electrostatic ignition sensitivity of the XM15/XM165 clusters and the E8 launchers during manufacturing, handling and deployment.

Phase I studies consisted of the following:

A. An explanation of electrostatic charge accumulation, ignition and discharge theories.

B. Measurement and tabulation of the XM15/XM165 material characteristics.

C. Evaluation and discussion of potential electrostatic hazards.

D. Development of "Equivalent Electrical Circuits" for the munitions in question.

E. Development of a test plan for Phase II.

Phase II studies reported herein comprise the results of the following activities:

A. Electrostatic spark ignition sensitivity tests of subsystems and components of the CS XM15/SM165, and of the E8 munitions.

B. Evaluation of prior incidents involving subject munitions (those suspected of being due to electrostatic discharge mechanisms).

C. Analysis and refinement of Equivalent Circuit data developed in Phase I.

D. Recommended component or subsystem "fixes" to eliminate or minimize the hazard of electrostatic ignition.

E. Development of the Phase III test program.

The Phase III test program will comprise the following:

A. Demonstration (functioning) of complete items by mechanisms predicted and evaluated from Phases I and II tests and studies, under typical environmental conditions.

B. Demonstration of the efficiency of recommended "fixes", modifications, etc. , by survival of modified items in the environment established in paragraph 1.

C. Recommendations for further corrective action/studies as appropriate.

IN SUMMARY

This program as completed to date has outlined the potential (and most probable) mechanisms for inadvertent ignition by electrostatic discharge; has described the manner in which electrostatic charges accumulate, migrate and discharge; evaluated proposed fixes; and recommended further modifications and tests, as appropriate.

PRINCIPAL FINDINGS

Both munitions systems are sensitive to electrostatic ignition by charges of the order of magnitude available in the normal processing, storage, or deployment environment.

Fixes suggested for the XM15 as a result of tests conducted at Dugway Proving Ground, i. e., substitution of aluminum for plastic junction blocks, while decreasing the electrostatic sensitivity of the system to one mode of ignition do not offer sufficient protection for all modes.

Several portions of the circuits of the munitions are susceptible to ignition by sparks whose energy is within the range to which humans can become charged.

Charged accumulation and migration characteristics of the components are such that repeated discharges to the munition by charges borne by personnel or operating equipment can result in functioning.

Certain components are extremely sensitive to electrostatic spark discharge; e. g., "the delay fuse if subjected to spark discharge to the center of the core can be ignited with as little as 0. 00001 joule" (compared to a typical human discharge value of 0. 1 joule). Igniter pellets can be ignited with as little as 0. 001 joule.

"Dusting" of the ignition pellets can cause extreme sensitivity (approximately 0. 00001 joule).

Ignition sensitivity of the delay fuse and junction block assembly is very dependent upon the quality of the electrical contact between the fuse and junction block. Positive contact increased ignition threshold levels to 10 to 50 joules whereas poor contact caused by insulation by RTV compound increased sensitivity to 0. 5 joule (in a typical case).

Final application by another organization, of conductive cement to the delay line - junction block interface, resulted in ignition threshold levels of 0. 05 to 0. 5 joule, much lower than expected, due to poor adhesion of cement, or possibly to formation of a lacquer film barrier.

RECOMMENDATIONS

The problem of electrostatic ignition of subject munitions is severe and requires the optimum in operating disciplines. A few general observations follow:

1. Good "Electrostatic" grounding techniques must be followed in all phases of manufacture, storage, deployment ("Electrostatic" grounding rather than single wire ohmic grounding techniques).

2. Operations should be conducted under conditions of maximum humidity concomitant with production/storage processes.

3. Electrostatic charge reducing sprays should be utilized where feasible.

4. Positive electrical contact should be assured between junction blocks and fuse lines on the XM15/XM165 munitions. A low impedance buss bar as described further herein is recommended.

5. Outer containers of XM15 and E8 munitions should be made of conductive material.

6. Aluminum junction blocks and conductive cement should be employed in XM15/XM165 munitions.

7. Materials utilized for all such munitions should be selected with maximum consideration of the relative positions of the materials in the triboelectric series - to minimize charge development.

8. Subject munitions should also be evaluated from the standpoint of Radio Frequency initiation susceptibility, utilizing the simulator/computer program developed at the Electronic Laboratories or similar techniques.

A detailed discussion of Electrostatic charge accumulation, migration and discharge theory will be found elsewhere in this report.

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1.1 BACKGROUND

In accordance with the requirements of Contract NAS8-23524, Amendment 7, GE-MTSD has performed Phase II of a two-phase program to investigate the electrostatic vulnerability of E8 and XM15/XM165 clusters. To assist the reader in evaluating completion of the contract requirements, a contract compliance guide is included in Table 1-1.

Phase I consisted of identification of the characteristics of the E8 and XM15/XM165 systems which affect their electrostatic vulnerability and a survey of the manufacturer's facilities. The objectives of Phase I were to:

- Identify areas of potential electrostatic hazards.
- Collect all available literature and information related to this study.
- Construct equivalent electrical circuits to facilitate analysis and interpretation of the data.
- Define the Phase II test plan.

Phase II includes the implementation of the test plan detailed in Section 7 of the Phase I report, GE-MTSD-R-052. The objectives of Phase II were to:

- Conduct electrostatic spark ignition and triboelectrification tests on subsystems and components of the E8 and XM15/XM165 clusters.
- Evaluate prior incidents of the E8 and XM15/XM165 clusters from an electrostatic viewpoint.
- Refine the equivalent electrical circuits generated in Phase I.
- Recommend measures to eliminate or neutralize hazard areas.
- Propose a future system test program.

To accomplish these objectives, Phase II was divided into five tasks, one for each objective. The tasks were implemented as shown in the Phase II logic diagram, Figure 1-1.

1.2 RATIONALE

There is sufficient evidence to suggest that the E8 and XM15 tactical CS dispersion weapons are vulnerable to premature activation by electrostatic accumulation and discharge. Results of an investigation into an accident involving an XM165/XM15 at Dugway gives credence to suspicions that an electrostatic discharge prematurely activated the weapon. Similarly, a fire at a facility manufacturing the E8 appears to have resulted from the same type of malfunction.

Table 1-1. Contract Compliance Guide

As specified in paragraph 1.2 of Amendment 7 to contract NAS8-23524 with NASA/MTF, the work scope for Phase II of the electrostatic vulnerability program is as follows:

Phase II Work Scope	Sections Applicable
a. Conduct the test plan generated in Phase I Final Report as accepted by the government after authority to proceed is provided by the Contracting Officer.	a. Sections 3, 4, and 5
b. Recommend measures (design or process changes) to eliminate or neutralize hazards areas, including determination of positive grounding and such other measures judged appropriate.	b. Section 6
c. Evaluate prior incidents in view of test results and recommendations.	c. Paragraphs 5.3 and 5.4
d. Refine electrical equivalent circuits.	d. Paragraph 2.3
e. Propose a future test program, including time and cost estimates, which will verify the assumptions generated in Phase II by means of tests on completely assembled inert and/or agent loaded E8 and/or XM15/XM165 canisters which incorporate the changes recommended in Phase II.	e. Section 7 (and Phase III Proposal)

The series of tests comprising Phase II should prove or disprove suspicions that the E8 and XM15 are indeed sensitive to electrostatic energy. These tests were conducted under laboratory conditions to assure control of the test environment, with the test configurations simplified as much as possible.

1.3 OBJECTIVE

The objective of these tests were to determine the electrostatic sensitivity of the E8 and XM15, to isolate sources of electrostatic generation either internally or externally, and to determine ways of decreasing or eliminating the possibility of premature ignition.

1.4 SCOPE

During Phase II, testing was confined to two general areas:

- Susceptibility of E8 and XM15 pyrotechnic materials to electrostatic ignition
- Susceptibility of E8 and XM15 structural materials to triboelectrification

The ignition tests were limited to components and subsystem configurations of the E8 and XM15 fuse systems. The triboelectrification tests included only those structural materials of the E8 and XM15 which are good insulators and consequently possible static electric accumulation surfaces. The logic diagrams delineating the tests required to meet these objectives are presented in Figures 1-2 through 1-5.

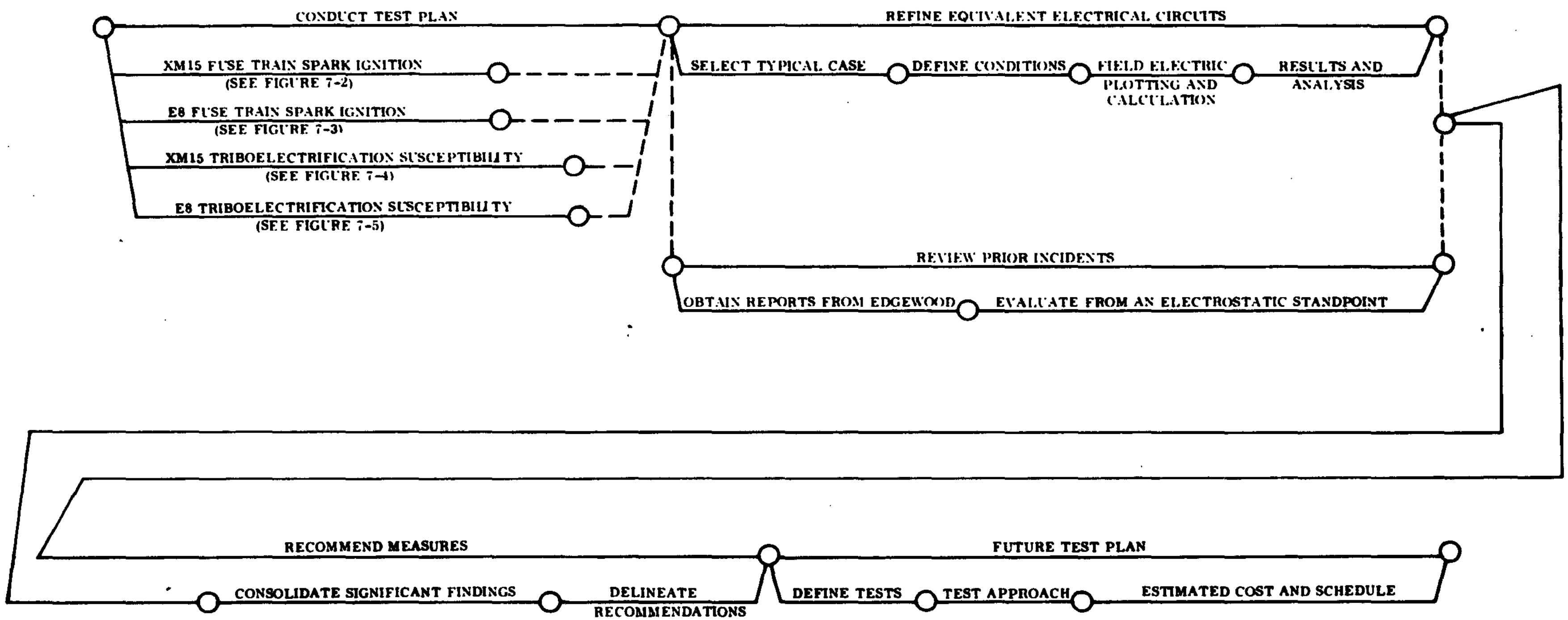


Figure 1-1. Phase II Logic Diagram

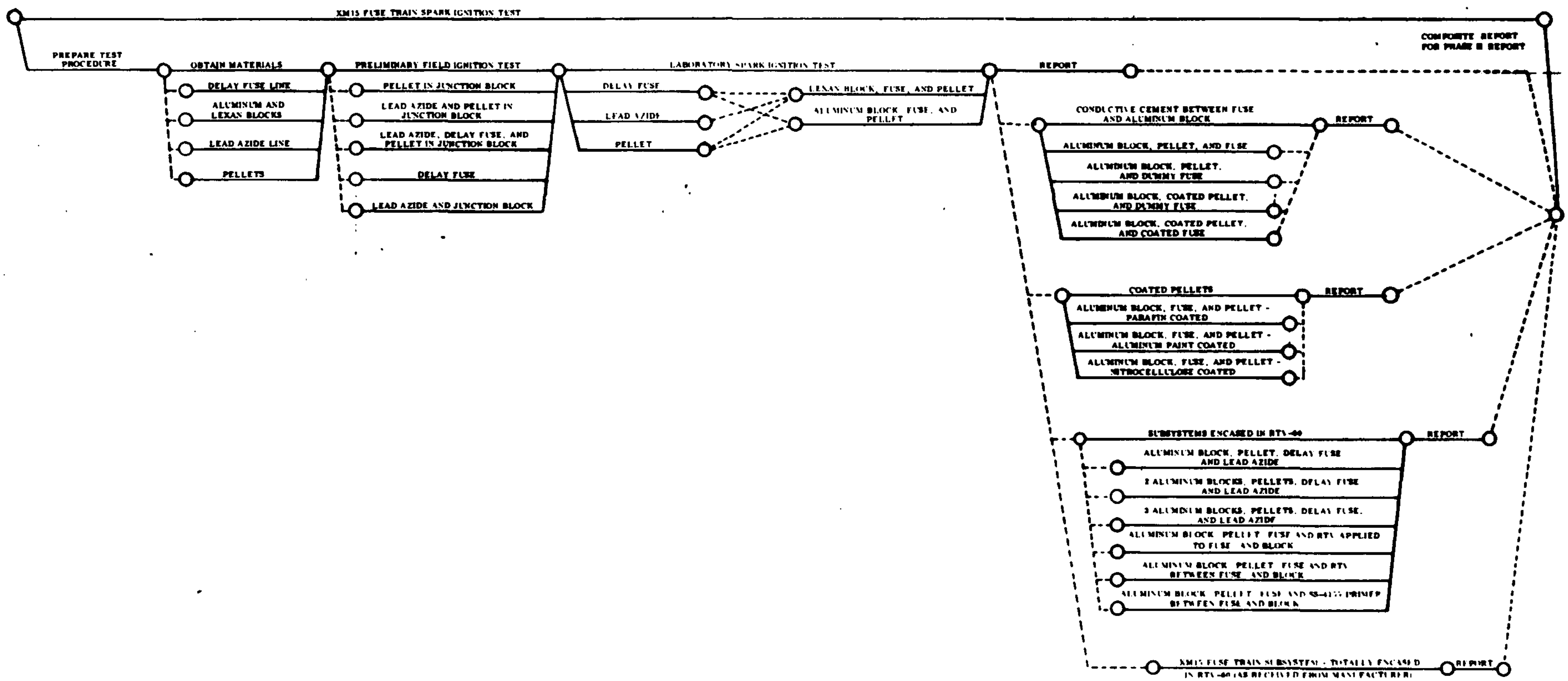


Figure 1-2. XM15 Fuse Train Spark Ignition Tests

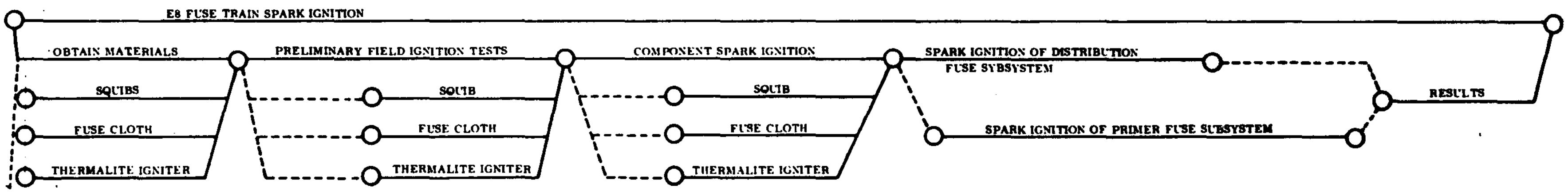


Figure 1-3. E8 Fuse Train Spark Ignition Tests

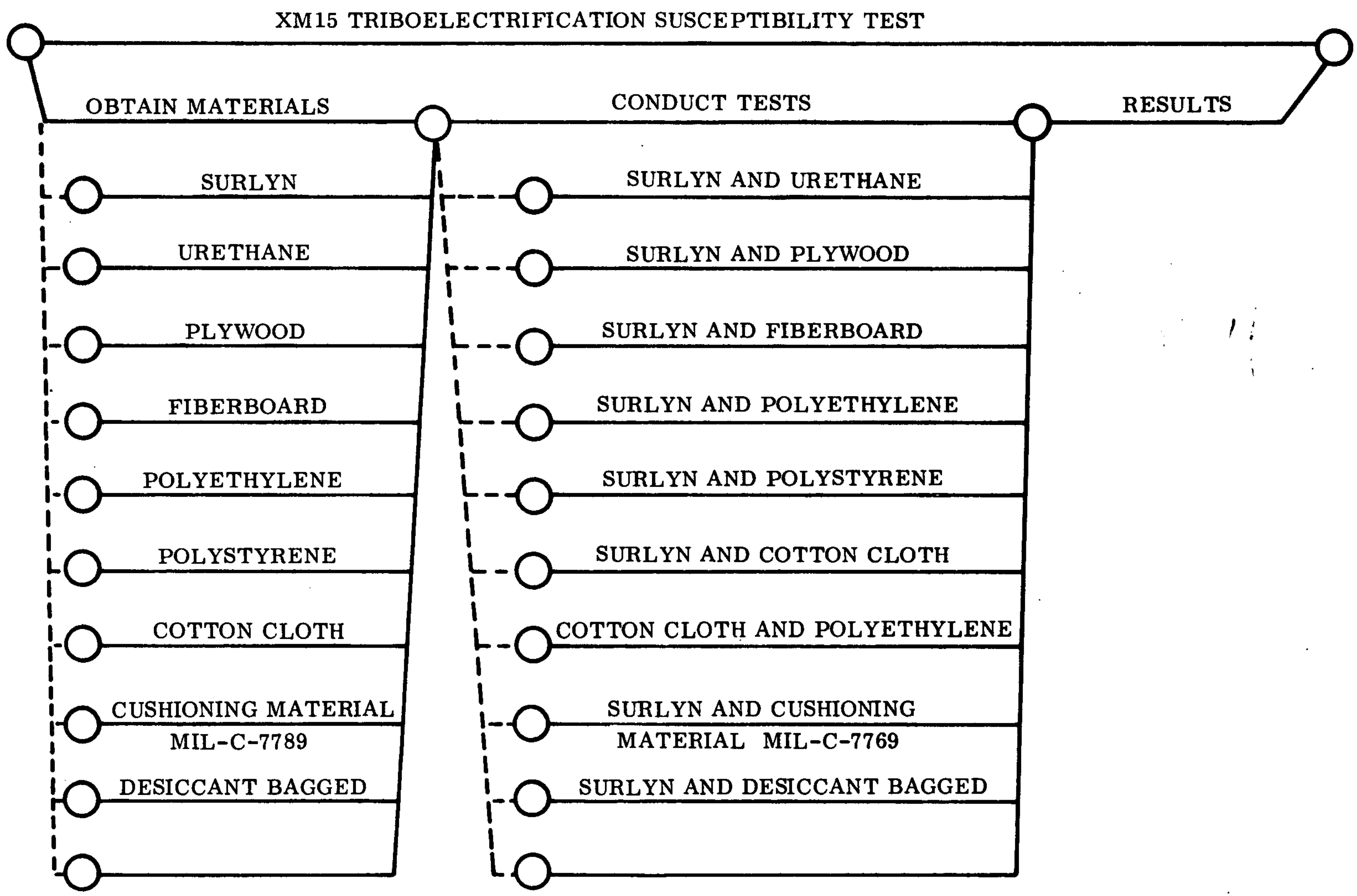


Figure 1-4. XM15 Triboelectrification Susceptibility Test

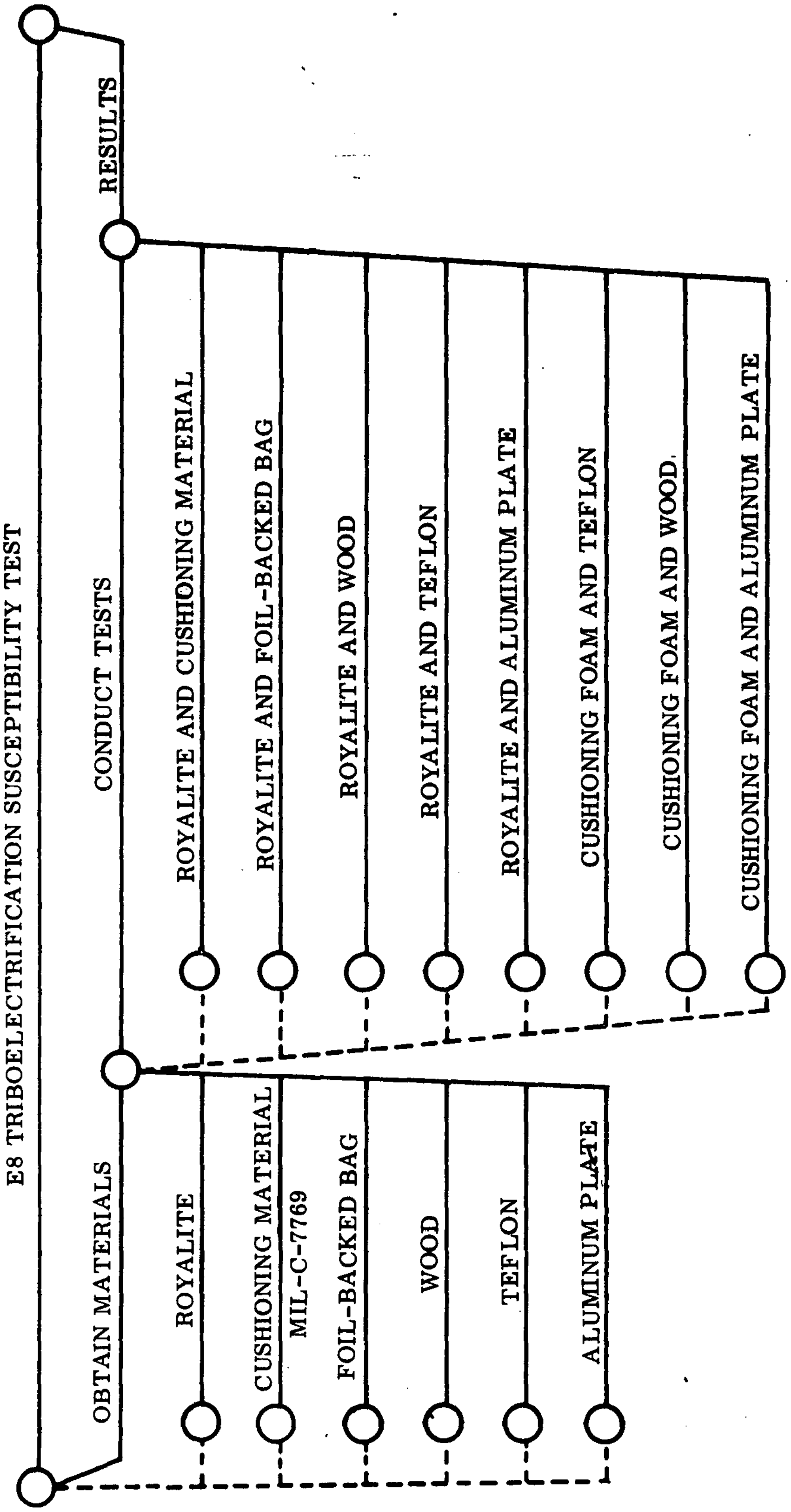


Figure 1-5. E8 Triboelectrification Susceptibility Test

SECTION 2
THEORETICAL DISCUSSION

2.1 GENERAL

The material contained in this section is an extension of the theoretical sections (2, 3 and 6) of the Phase I report (GE-MTSD-R-052) and includes a summary review of electrostatic phenomena, a general equivalent circuit analysis, and suggestions for refinement of the specific equivalent circuits of the E8 and XM15/XM165 systems.

2.2 ELECTROSTATIC PHENOMENA

The following paragraphs include a review of Section 3, "Electrostatics," of the Phase I report.

2.2.1 GENERAL

A spark, capable of inducting ignition of pyrotechnic materials, is the culmination of a prerequisite sequence of events. The spark conditions must be such that an electric field across a gap (voltage/gap distance) must be generated which exceeds a characteristic breakdown field of the material within the gap. Therefore:

- A separation of charge must occur to produce the potential.
- A gap must exist.
- The potential must be induced on or transferred to the gap.
- The gap environment must be such that charge is not bled away at a greater rate than it is being applied.
- The electric field within the gap must equal or exceed the dielectric strength of the material within the gap.

In addition, if ignition is to occur:

- The material within the gap must be ignitable or able to transfer the spark's heat to ignitable material.
- The energy of the spark must be sufficient to generate a self-sustaining "hot spot" (material dependent).

This chain of events (shown graphically in Figure 2-1) will result in initiation of the reactable material. Initiation is the first element in the ICT sequence (Doc. 59, Section 8) of accident progression. An evaluation of the other elements, communication and transition, is beyond the scope of this discussion. Instead, the prerequisite initiation sequence will be further clarified, albeit somewhat naively where necessary for clarity's sake.

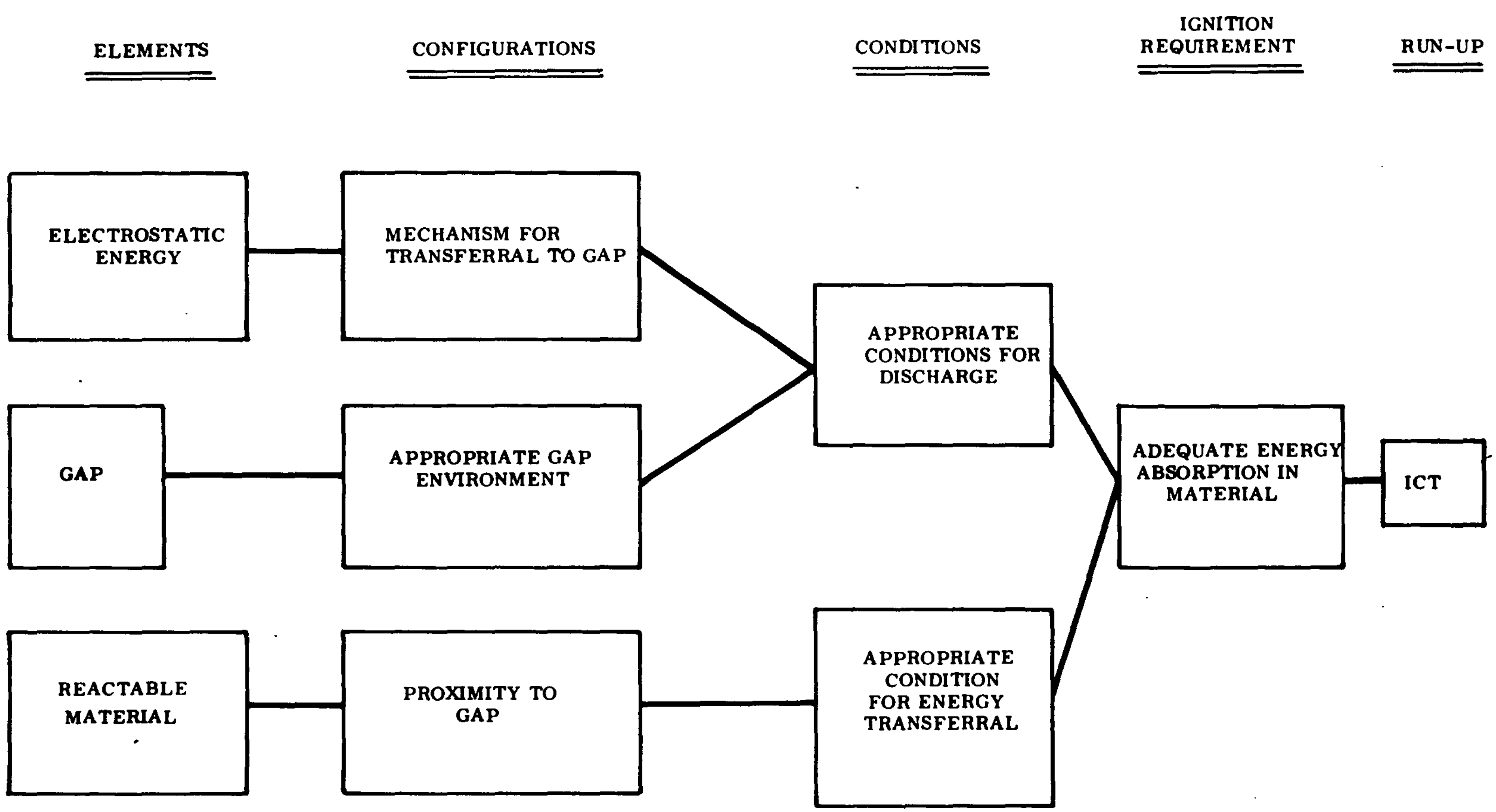


Figure 2-1. Prerequisite Initiation Sequence

2.2.2 MECHANISM OF CHARGE SEPARATION

Charge separation occurs as a natural result of friction between two materials. This is referred to as a triboelectric effect (discussed in detail in the Phase I report) because of its predominance as a mechanism for production of special separation of electrons (negative) from their "holes" (positive) formerly occupied to produce a null net charge.

Other mechanisms such as chemical or physical processes which result in separation of charge exist but occur in special situations only.

2.2.3 GAP REQUIREMENTS

A gap for the spark to transverse is an obvious necessity. The characteristics of the gap greatly affect the discharge characteristics. The gap may be between insulating materials, conducting materials, or one of each. The electrodes forming the gap are separated by a certain distance, but for this gap to break down it must be close enough so that discharge will occur here rather than at another location which would discharge the original gap. In general, the gap separation may also be a function of time.

The electrode shapes also affect discharge characteristics. For example, needle-shaped electrodes in air break down at much lower voltages than do parallel plate electrodes because of field emission effects which ionize the air surrounding the point, in turn effectively decreasing the electrode spacing (densely ionized air is conductive).

2.2.4 POTENTIAL ACROSS GAP

The gap must have a potential across it before a breakdown can be induced. Electric potential at a location $\vec{r}$ is defined as

$$V(\vec{r}) = -\frac{1}{\epsilon} \sum_{i=1}^{m} \frac{q_i}{|\vec{r}_i - \vec{r}|}$$

where q_i is the charge located at $\vec{r}_i$ of a total of M charge locations. The dielectric constant is ϵ.

There is a large potential close to a concentration of like charge. The electric field is

$$\vec{E}(\vec{r}) = \frac{1}{\epsilon} \sum_{i=1}^{m} \frac{q_i(\vec{r}_i - \vec{r})}{|\vec{r}_i - \vec{r}|^3} = -\text{grad } V(\vec{r}).$$

A charged particle of charge q located at $\vec{r}$ is subjected to a force

$$\vec{F} = \vec{E}(\vec{r})\, q.$$

Thus large potential gradients (electric fields) produce large forces on charged particles within the field. The electric field within a gap with a potential drop of ΔV between planar parallel electrodes separated by a distance D is $\Delta V/D$ (neglecting fringing fields). Thus the electric field can be increased by decreasing the gap separation or by increasing the potential drop (voltage) between the electrodes.

When the electric fields are sufficient to separate bound charges (ionization), the charged particles are accelerated by $\vec{E}$. The accelerated particles interact with other bound charges, sometimes imparting sufficient energy to separate the new pair. This process cascades into an electric breakdown. Excess charge can then easily flow between electrodes through the ionized material, thereby reducing the electric field and in turn quenching the spark. (Streamer theory of spark production is discussed in the Phase I report.)

Thus it is necessary to induce charge directly on the gap electrodes or to transfer the charge to the electrodes from another part of the system or from an external system.

2.2.5 ENVIRONMENT

Charge will move along conductive paths under the action of electric fields. Therefore, excess charge will move along a conductive path to ground or to neutralize an opposite charge. If the electrodes are not isolated but are electrically interconnected, then charge will not accumulate on the electrodes. If the connection has a high resistance, the charge may accumulate faster than it can be bled off; thus low impedance connections are recommended in all such situations.

The conductivity of air is a function of the humidity. Since air surrounds all exposed surfaces, it is common practice to maintain conditions of high humidity to provide conductive paths between exposed components and ground potential.

2.2.6 BREAKDOWN

The phenomena of breakdown was introduced in paragraphs 2.2.3 and 2.2.4 of this report. The dielectric strength of a material defines the minimum potential gradient which induces breakdown (usually expressed in volts/mil). These values vary greatly with material.

2.2.7 IGNITION

The ignition sensitivity to electrostatic discharge is material dependent. Since ionization occurs, the temperature within the spark is at levels common to plasmas. If the requirement for ignition were that the ignition temperature at some point within the reactable material be exceeded, then ignition would occur with any spark which penetrates the material. However, the lower range of spark energies are not sufficient to induce ignition as explained in the following paragraph.

2.2.8 IGNITION REQUIREMENTS

If the energy of a spark is $\mathcal{E}$ across a gap of separation D, most of $\mathcal{E}$ is transferred to the material between the gap. The energy is localized to a region within a mean radius R of the center of the spark. The value of R is a result of balancing the effect of magnetic constriction of the moving charge which attempts to minimize R with the repulsive forces between like charges which attempt to maximize R.

The "hot spot" theory of ignition predicts that ignition will not occur until there is a critical

concentration of energy within the material. If the "hot spot" dimensions are of the order of R, then the energy in the hot spot is proportional to $\mathcal{E}/D$ as shown in Figure 2-2. Neglecting resistive losses, the energy of the spark is equal to the energy discharged. The energy discharged is the product of the charge transferred and the voltage that it is accelerated through. Since breakdown occurs at a characteristic voltage for a given gap, the energy is increased by increasing the available charges.

In general, the energy which is applied to a system is negligable during the period of the spark; therefore, the charge available for discharge must be previously deposited. If a charge Q is available to each electrode and induces a voltage V across the gap, the system has a capitance $C = Q/V$ and an energy $\mathcal{E} = 1/2QV = 1/2CV^2$. (The factor of 1/2 is included since the capacitor formed by the system can be completely discharged by exchanging 1/2Q from each electrode.)

The charge available from insulating electrodes is that which is in the vicinity of the spark. If the electrodes are conductive, charge can be transferred along all available conductive paths to the electrodes. Therefore, if a capacitor C' charged to V' is electrically connected across the gap, a potential V with capacitance C, the voltage across C and C' is $\left(\frac{CV^2+C'V'^2}{C+C'}\right)^{1/2}$ and a charge of CV+C'V'. Thus a benign situation may be transformed into a dangerous one by application of an external charged capacitor; e.g., if V=O, $C \ll C'$, then

$$Q = O \rightarrow C'V'$$
$$V = O \rightarrow \sim V'$$

Electrostatic energy can be stored in the conductive components of the system as a result of capacitive coupling to charge bound in the neighboring insulating components. The charge induced on the conductors via capacitive coupling is referred to as a mirror charge.

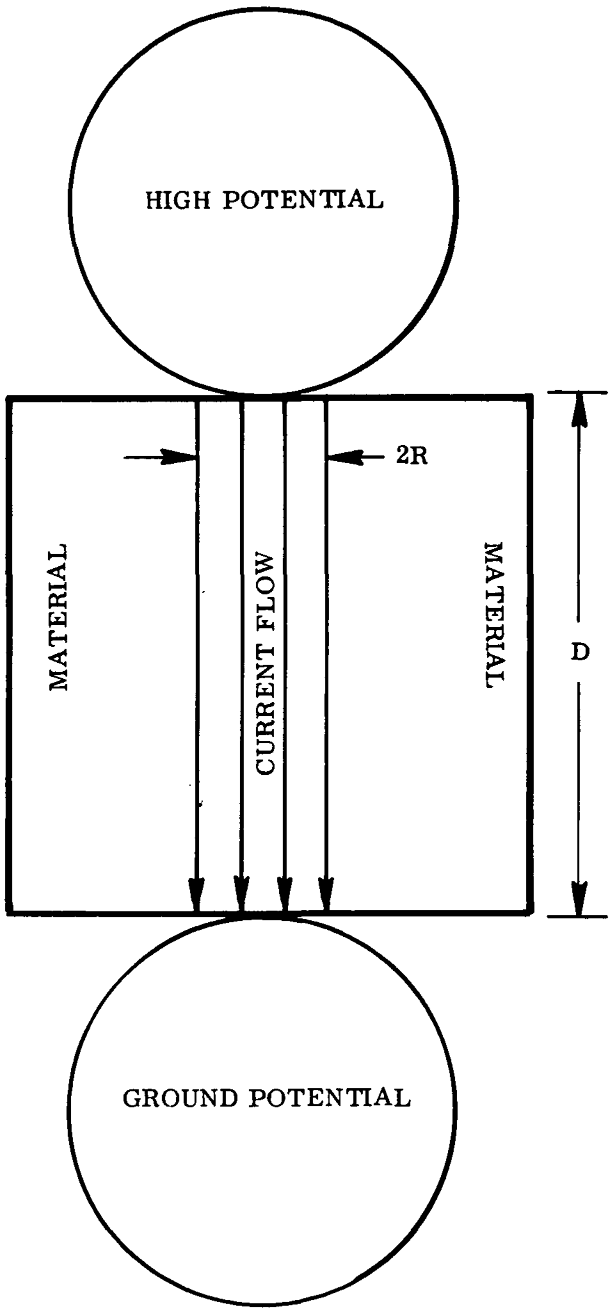
Once the mirror charge has accumulated it will not participate in a discharge current (or othe: transient current) since it is coupled to immobile bound charge. On the other hand, a rapid charge in the bound charge distribution (such as by further accumulation by transfer or tribo-electric effects or reduction by sloughing off of charged insulating material) may induce significant currents in the conducting parts when the charge is redistributed to compensate for non - equilibrium conditions of the mirror charge. Equilibrium conditions exist when the system's electrostatic energy is minimized.

The two generic classes of situations which would induce electrostatic initiation in the E8 and XM15/XM165 systems are the inadvertent application of an external energy source across internal gaps via conductive paths and the discharge of internal charge accumulations across critical gaps.

2.3 EQUIVALENT CIRCUIT DISCUSSION RELATED TO DISCHARGES

2.3.1 GENERAL

Over long periods of time (seconds or greater), the net charge which flows through semicon-



Spark Volume
$= \pi R^2 D$
Spark Energy $= \mathcal{E}$
Energy Density $= \dfrac{\mathcal{E}}{\pi R^2 D}$

Assume "hot spot"
Volume $\approx 4/3 \, \pi \, R^3$

$\therefore$ Energy per "hot spot"
$\approx \dfrac{R}{D}\mathcal{E} \propto \dfrac{\mathcal{E}}{D}$

Figure 2-2. Model of Spark Ignition Criteria

ducting or near semiconducting materials may be significant. A short duration (microseconds or less) pulse of current when presented with several paths will distribute itself among the paths according to their impedance. Only an insignificant fraction will flow through a high impedance path if a much lower impedance path is accessible. Thus, while semiconducting resistances are significant when related to electrostatic distribution of charges (as discussed in the Phase I report), only the low resistance elements are significant for discharge phenomena, since they are typified by short duration pulses. Examples of high and low resistant materials and components are listed in Section 4 of the Phase I Report.

One critical difference between conventional low current pulses and high current pulses is that some elements of a circuit which would present a high impedance to a low current will break down under higher voltages and present a much lower resistance than initially. Thus, the equivalent circuit is vastly changed via the breakdown. Of course, if the breakdown occurs near reactive material, ignition may occur; but this is a different factor and is discussed elsewhere.

Another factor to consider is that short duration pulses are composed of high frequency Fourier components; therefore, the complex component of a path's impedance may be significant. Thus inductances and capacitances may be significant in affecting the effective impedance.

2.3.2 EQUIVALENT CIRCUIT DISCUSSION

In its most simplified form an equivalent circuit surrounding a gap in any conductive network is as shown in Figure 2-3A.

Where C_G is the capacitance of the gap and any parallel circuits, R_p represents the total resistances of parallel circuits, R_s is the total internal and external series resistance, and C is the total internal and external series capacitance. Inductances are assumed negligable. Note that C includes any externally applied capacitance as discussed in paragraph 2.2.8.

Consider, for example, the XM15 fuse train. The most reasonable gap in this example is the gap, filled with RTV, between a delay fuse and a junction block. A typical value of C_G for this gap is 10pF ($10^{-5}\mu F$) as determined by measurements of several insulated delay fuse-junction block capacitances. This capacitance is too small to significantly affect the equivalent circuit.

The next question to be answered is whether it is too small to store sufficient energy to ignite a unit. Assuming a relative dielectric constant of 2 for the RTV and an effective area of 0.5 cm^2, the average spacing can be calculated from the formula

$$C = 0.09 \epsilon \frac{A}{D} ,$$

where C is in pF. Thus

$$D = \frac{0.09 \times 2 \times 0.5}{10} \approx 0.01 \text{ cm}$$

The minimum spacing (where breakdown would occur) may be $\sim 1/2$ D or 0.005 cm. The dielectric strength of RTV is 600 volts/mil or $\sim 2 \times 10^5$ volts/cm; thus the maximum energy which could be stored in such a capacitor is

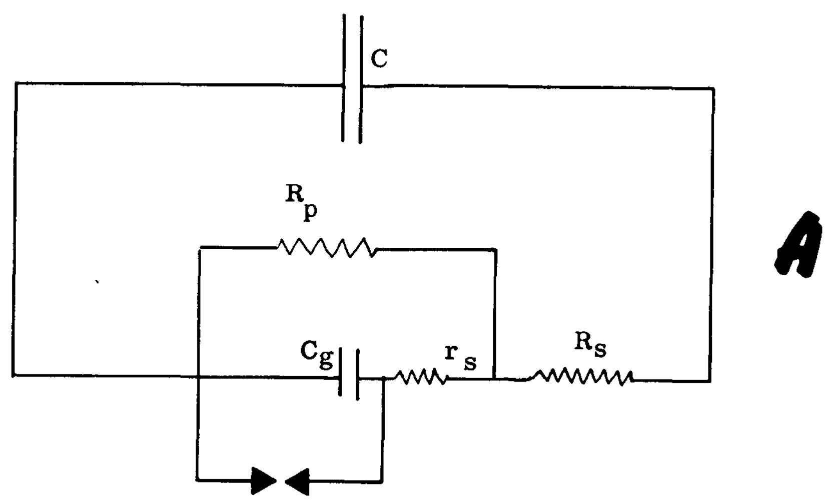
$$E_{max} = 1/2\, C_G V^2_{breakdown} \approx 1/2 \times 10^{-11} \times (10^3)^2 = 5\ \mu\text{joule}.$$

This energy is insufficient to ignite any of the reactable material (see Section 3); thus the capacity of the gap between the delay fuse and junction block, C_G, can be neglected as both an element of the equivalent circuit (as per Figure 2-3B) and as a significant energy storage component.

2.3.3 SOLUTION OF THE XM15 FUSE TRAIN EXAMPLE

In order to develop an easily comprehendend formalism for solution of discharge characteristics in the XM15 fuse train, a simplified heuristic approach will be applied.

For purposes of discussion, C will be assumed to be charged to a voltage V_o ($\mathcal{E}_c = 1/2 C V_o^2$); then,



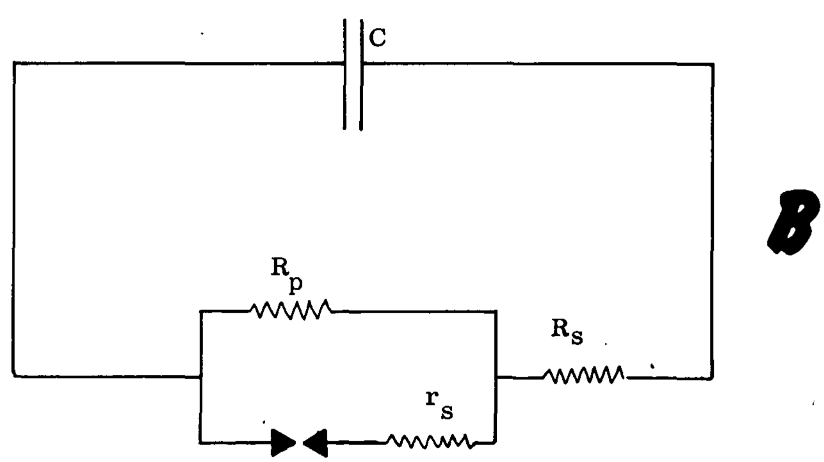


Figure 2-3. Equivalent Circuits Applicable to Discharge Pulses

at time t = 0, it is discharged into the remainder of the circuit. The instanteous voltage across the gap is

$$V_G\,(t = 0) = V_o \, \frac{R_p}{R_p + R_s}\,.$$

If the breakdown voltage of the gap exceeds V_G (t = 0), then no spark occurs and C is discharged with a time constant $C(R_p+R_s)$.

If $V_G(t=0)$ exceeds the breakdown voltage, then a discharge does occur and for the duration of the spark the effective gap resistance (R_G) will be small, but still most likely $R_G >> r_s$.

The discharge time constant would be $C\left(\frac{R_pR_G}{R_p+R_G} + R_s\right)$.

The voltage across R_G is

$$V_G(t) = V_o(t)\,\frac{\frac{R_pR_G}{R_p+R_G}}{\frac{R_pR_G}{R_p+R_G} + R_s} = V_o\,(t)\,\frac{R_pR_G}{R_pR_G + R_pR_s + R_GR_s}$$

The power dissipated in the spark is

$$\mathcal{E}_G(t) = \frac{V_G^{\,2}(t)}{R_G}\,.$$

The fraction of the total energy stored in C which is dissipated in the spark, assuming the spark is formed at t = 0, R_G remains constant, and the spark duration extends over several time constants (all assumptions are at best only approximate), is

$$\frac{\mathcal{E}_G}{\mathcal{E}_c} = \frac{Vg^2/R_g}{V_o^{\,2}\left(\frac{R_pR_G}{R_p+R_G} + R_s\right)} = \frac{\frac{R_p^{\,2}R_G}{(R_p+R_G)^2}}{\frac{R_pR_G}{R_p+R_G} + R_s} = \frac{R_p^{\,2}R_G}{R_pR_G(R_p+R_G) + R_s\,(R_p+R_s)^2}$$

An interesting note is that the extremum (maximum or minimum) gap energy occurs when $\frac{\partial}{\partial R_G}\left(\frac{\mathcal{E}_G}{\mathcal{E}_c}\right) = 0\,.$

Solution of the equation yields the result that this condition is met when

$$R_G = R_p\,\sqrt{\frac{R_s}{R_s + R_p}}\,.$$

2.3.4 XM15 EQUIVALENT CIRCUIT COMPONENT ESTIMATIONS

2.3.4.1 General

The effort covered by this paragraph consists of estimating some of the component values of the XM15 clusters equivalent circuit. Such estimations were determined by calculations performed with dimensioned surfaces obtained from system and component mechanical drawings. Such estimations will provide insight into the more critical areas of the XM165 whereby realistic measurements may be performed and methods of solving the critical area problems tried and evaluated. The estimations provided in this report are to be considered preliminary and are part of the first step in the system evaluation. The accuracy of the component estimations are expected to be enhanced by a comprehensive measurements analysis.

2.3.4.2 Technical Results

The values of capacity and resistance calculated for the equivalent electrical circuit in this section are, admittedly, of limited accuracy. However, the important consideration here was assumed to be to provide some justification from an electrical circuit approach for the observed equipment failures thought to be due to electrostatic discharges. Because of the complicated physical structure of the conductors and insulating materials in the equipment it was necessary to make some simplifying assumptions regarding the actual physical layout in order to be able to compute electrical values of capacity and resistance and to consider only those electrical paths or configurations having the most significant effect on electrical values.

2.3.4.2.1 Method of Analysis

The values of the resistances and capacities for the equivalent circuit were determined by employing conventional methods of calculation. The thorough determination of the equivalent circuit parameter values by employing such advanced techniques as electrostatic field plotting and the ATLAB computer program were not considered to be justifiable after the significant effect of mechanical tolerances on electrical values was appreciated. The significant (for this study) tolerances specified for component dimensions would introduce uncertainties which exceed the precision of conventional calculational techniques; therefore, the more sophisticated techniques will not be applied to these data. The most prominent example of the mechanical tolerance effect is the possible radial spacing between the central delay fuse section and the small junction block which has a possible range of zero to 0.005 inch and thus a very significant effect on the capacity and resistance between the fuse and block.

2.3.4.2.2 Capacitance and Resistance Calculations

Nominal dimensions have generally been used in performing the following calculations of capacity and resistance existing in several areas of the equipment. Other assumptions affecting the conditions defined to facilitate the calculations are stated where appropriate.

The calculated values of resistance and capacitance are for the equivalent circuit defined by Kirchner (Doc. 56, Section 8) and reproduced in Figure 2-4. The condition which produces this particular equivalent circuit is that neither the central delay fuse section nor the line igniter makes metallic contact with the left small junction block. This condition results in the division of the conducting parts into two groups defined by Kirchner as:

Group 1

Left large junction block
Left small junction block
Left two sections of delay fuse
Left eight igniters fuses

Group 2

Right large and small junction blocks
Center and two right delay fuse sections
Line igniter
Strongback and timer
Sealing wires numbers 5, 6 and 7

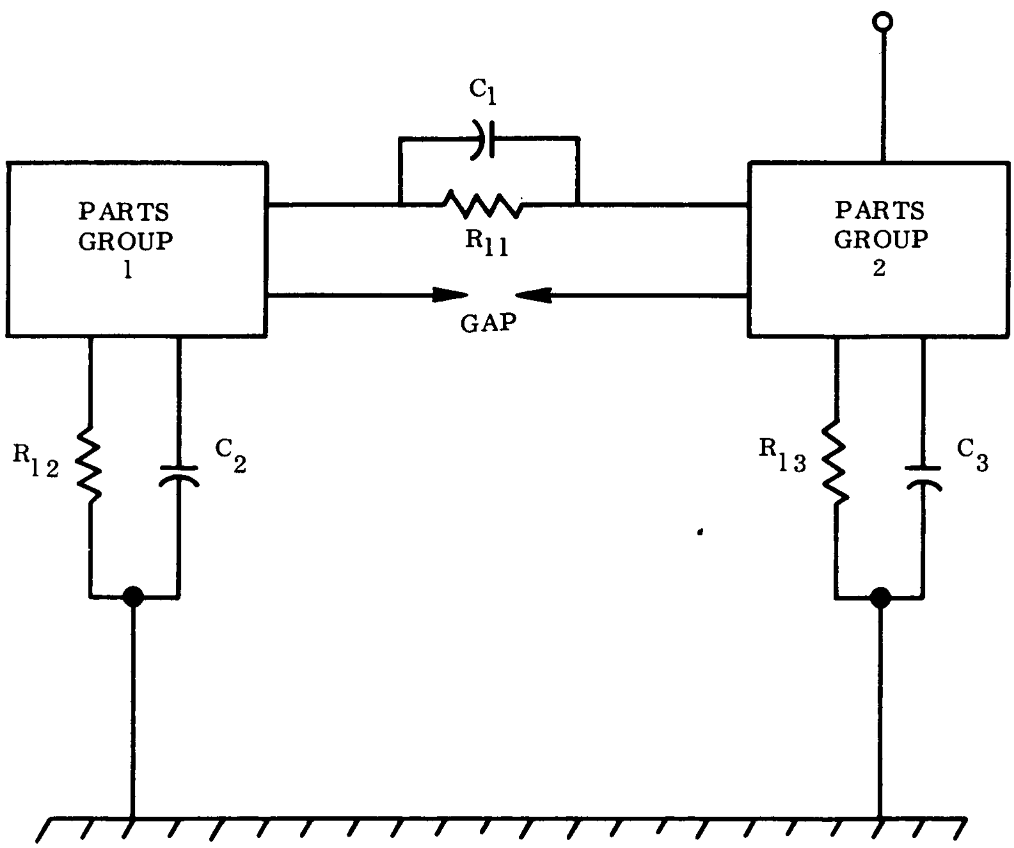


Figure 2-4. Equivalent Circuit of XM15

2.3.4.2.2.1 Capacitance C_1. The capacitance C_1 is composed of several component capacities as follows:

- The capacity between the central delay fuse section and the left small junction block.
- The capacity between the line igniter and the left small junction block.
- The capacity between the strongback and the left large and small junction blocks and the left eight igniter fuses.

In calculating the values of the components of capacitance C_1, it will be assumed that the dielectric in all bases is RTV-60 silicone rubber, the implicit assumption being made that the RTV flows into the space between the delay fuse and the left small junction block and between the line igniter and the left small junction block. It is further assumed that the clearance between both the fuse and igniter and the junction block is constant both peripherally and axially.

2.3.4.2.2.1.1 Capacity Between Central Delay Fuse Section and the Left Small Junction Block. The capacity between the delay fuse and the small junction block can be calculated by using the formula for a parallel plate capacitor as the spacing is small compared to the diameter of the fuse. The pertinent dimensions are:

- Delay fuse O.D. = 0.110"- 0.005"
- Hole in junction block = 0.110"+ 0.005"
- Depth of hole in block = 0.096" to 0.126"
- Dielectric constant of RTV-60 $\doteq$ 3.7

The capacity of a parallel plate capacitor is, in rationalized MKS units:

$$C = \frac{\epsilon_o \ \epsilon_r \ A}{d} \quad \text{Farads}$$

where: ϵ_o = permittivity of free space = 8.85×10^{-12} Farads/m

ϵ_r = relative dielectric constant of insulation between plates

A = area of plate, m^2

d = separation of plates (dielectric thickness), m.

For A in square inches and d in inches, the above equation reduces to:

$$C = 0.2248 \ \epsilon_r \frac{A}{d} \ \text{pF}$$

For the cylindrical surface being considered here,

$$A = \pi D \lambda \ \text{in}^2$$

where: D is the diameter of the surface, in.
ℓ is the length of the surface, in.

As indicated by the dimensions listed above, the difference in diameters of the delay fuse and hole varies between 0 and 0.01". Taking a mean value of 0.005", the corresponding plate spacing is 0.0025". The capacity, using a mean hole length, ℓ, of 0.111", is:

$$C_{1a} = 0.2248\ (3.7)\ \pi\ (0.110)\ \ (0.111)/0.0025\ \text{pF}$$
$$= 12.75\ \text{pF}$$

2.3.4.2.2.1.2 Capacity Between Line Igniter and Left Small Junction Block.

The pertinent dimensions of the interface between the line igniter and the left small junction block are:

hole in block : 0.060" + 0.006"
hole depth: 0.096" to 0.126"

No dimensions were available for the line igniter (Pyrocore) diameter. It was assumed to be 0.06 - 0.006 so that the mean difference is diameters of line igniter and hole is 0.006". The capacity is:

$$C_{1b} = 0.2248\ (3.7)\pi(0.06)\ \ (0.111)/0.003\ \text{pF}$$
$$= 5.8\ \text{pF}$$

2.3.4.2.2.1.3 Capacity Between Strongback and Group 1 Parts.

Reference to drawings E14-23-1895, -1899, and -1908 indicates that the bottom surface of the strongback sits on the top surface of the cluster shell assemblies and thus its position in relation to the Group 1 part is known within the given tolerances. The surface of the RTV-60 silicone rubber is spaced 0.15" + 0.12" below the top surface of the cluster shell assembly, or the bottom of the strongback. In the following calculations of capacity this spacing will be assumed to have a nominal value of 0.20". Thus, 0.20" of the spacing between the strongback and the Group 1 parts will be air dielectric and the remainder will be RTV-60. Where two materials having different dielectric constants are used between the plates of a parallel plate capacitor, the capacity is

$$C = 0.2248A\ \frac{\frac{\epsilon_1}{d_1}\cdot\frac{\epsilon_2}{d_2}}{\frac{\epsilon_1}{d_1}+\frac{\epsilon_2}{d_2}}\ \text{pF}$$

where the subscripts denote the two materials and A, the plate area in in^2, is the same for each material.

The individual parallel plate capacitances between the strongback and the small junction block, the large junction block and the projected area of the time delay and igniter fuse sections will be calculated and summed to obtain the total for this particular component of capacity C_1.

The left small junction block has an area facing the strongback of 0.65" x 0.46" and is separated from it by approximately 0.5" of RTV-60 and 0.2" of air. The capacity is thus:

$$C_{1c,1} = 0.2248\,(0.65)\,(0.46)\,\frac{\frac{3.7}{0.5}\cdot\frac{1}{0.2}}{\frac{3.7}{0.5}+\frac{1}{0.2}}\ \text{pF}$$

$$= 0.2\ \text{pF}$$

The left large junction block has an area of 0.44" x 1.1" and the dielectric consists of 0.3" of RTV-60 and 0.2" of air. Its capacity to the strongback is:

$$C_{1c,2} = 0.2248\,(0.44)\,(1.1)\,\frac{\frac{3.7}{0.3}\cdot\frac{1}{0.2}}{\frac{3.7}{0.3}+\frac{1}{0.2}}\ \text{pF}$$

$$= 0.39\ \text{pF}$$

A total length of approximately 64 inches of delay fuse and igniter fuse is included in the left side of the XM15 cluster. The diameter of the fuse is 0.11" so the projected area is 7 in^2. The mean spacing of the fuses is 0.8" from the strongback and consists of 0.6" of RTV-60 and 0.2" of air. The capacity between fuses and strongback is:

$$C_{1c,3} = 0.2248\,(7)\,\frac{\frac{3.7}{0.6}\cdot\frac{1}{0.2}}{\frac{3.7}{0.6}+\frac{1}{0.2}}\ \text{pF}$$

$$= 4.34\ \text{pF}$$

The total component of C1 between the strongback and the Group 1 components is thus:

$$C_{1c} = 0.2 + 0.39 + 4.34 = 4.93\ \text{pF}$$

and the total C_1 is:

$$C_1 = 4.93 + 5.8 + 12.75 = 23.47\ \text{pF}$$

2.3.4.2.2.2 <u>Resistance R_{11}</u>

Resistance R_{11} in the equivalent circuit of Figure 2-4 shunts capacitance C_1. It is made up of the several resistance paths which exist between Group 1 and Group 2 conductors. The principal resistance paths generally coincide with the areas considered above in calculating the capacitance C_1.

2.3.4.2.2.2.1 Resistance Between Central Delay Fuse Section and the Left Small Junction Block. The resistance of the RTV-60 material assumed to occupy the space between the delay fuse section and the left small junction block is: $R_{11a} = \frac{\rho d}{A}$

Where ρ is the volume resistivity of the RTV-60; ($\rho = 13 \times 10^{14}$ ohm-cm.)

d is the length of the resistive path, cm

A is the cross sectional area of the resistive path, cm^2

The length, d, is equal to the radial spacing between fuse and junction block determined previously to be 0.0025" nominal. The area, A, is:

$$A = \pi D \ell = \pi (0.110) \ (0.111) = 0.0384 \text{ in}^2$$

The resistance is:

$$R_{11a} = \frac{(13\text{x}10^{14}) \ (0.0025) \ (2.54)}{(0.0384) \ (2.54)^2} = 3.33 \times 10^{13} \text{ ohms}$$

2.3.4.2.2.2.2 Resistance Between Line Igniter and Left Small Junction Block.

Using the dimensions derived previously and the procedure above, the resistance is:

$$R_{11b} = \frac{(13\text{x}10^{14}) \ (0.003) \ (2.54)}{(0.06) \ (0.111) \ (2.54)^2} = 7.35 \times 10^{13} \text{ ohms}$$

2.3.4.2.2.2.3 Resistance Between Strongback and Group 1 Parts.

There are several resistive paths, not independent, between the strongback and the Group 1 parts. They are:

- The two spring pads are located over the small and large junction blocks and make metallic contact to the adapter via the leaf springs. A direct resistive path is thus provided from the adapter to the junction blocks via the RTV-60 silicone rubber.

- The bottom of the aluminum adapter contacts the top of the surlyn cluster shell assemblies only on the lip which overlaps the adjacent shell assembly. Contact is made to the inside of the rails of the cluster shell assemblies by the sides of the adapter and on the outside by the cluster hinge clamp. By these means contact is made to the cluster shell assemblies and a leakage path exists through the surlyn material to the molded fuse assembly and via the RTV-60 silicone rubber to the fuse jackets and the junction blocks.

The resistance of the RTV-60 between the spring pads and the junction blocks will be assumed to be that resulting from an area equal to the area of the spring pad to account in part for the resistance between the pads and the igniter fuses adjacent to the junction blocks. The

numerical data is as follows:

- Spacing between small junction block and pad = 0.35 in.
- Spacing between large junction block and pad = 0.15 in.
- Net area of spring pad = 1.17 in^2
- Resistivity of RTV-60 silicone rubber = 13 x 10^{14} ohm-cm.

The resistance between the spring pad and small junction block is:

$$R_{11c} = \frac{\rho d}{A} = \frac{(13 \times 10^{14})\ (0.35)\ (.254)}{(1.17)\ (2.54)^2} = 1.53 \times 10^{14} \text{ ohms.}$$

The resistance between the spring pad and large junction block is:

$$R_{11d} = \frac{(13 \times 10^{14})\ (0.15)\ (2.54)}{1.17\ (2.54)^2} = 6.57 \times 10^{13} \text{ ohms}$$

Inspection of the cluster shell drawing, E14-23-1908, indicates that the path length through the surlyn material of the cluster shell between the bottom of the rail and a point to half the height of the RTV-60 silicone rubber of the molded fuse assembly is approximately 3/4". The mean length of the path through the RTV-60 to the fuses will be about 1/4". The thickness of the path through the surlyn will be 1/4" and that through the RTV-60 will be about 1/2". The extent of these paths along the length of the assembly is about 12 inches. The pertinent figures are listed below:

For the path through the surlyn:

$d = 0.75"$ $\qquad A = 0.25 \times 12 = 3 \text{ in}^2$

For the path through the RTV-60:

$d = 0.25"$ $\qquad A = 0.5 \times 12 = 6 \text{ in}^2$

The total resistance is the sum of the two resistances.

$$R_{11e} = \left.\frac{\rho d}{A}\right|_{\text{Surlyn}} + \left.\frac{\rho d}{A}\right|_{\text{RTV-60}}$$

$$R_{11e} = \frac{10^{15}\ (0.75)\ (2.54)}{3(2.54)^2} + \frac{(13 \times 10^{14})\ (0.25)\ (2.54)}{6(2.54)^2}$$

$$= 10^{14} + 0.21 \times 10^{14} = 1.21 \times 10^{14} \text{ ohms}$$

The total equivalent value of R_{11} is the value of the five components of R_{11} calculated above. This final value is

$$R_{11} = 1.36 \times 10^{13} \text{ ohms}$$

Table 2-1. Component Capacity Numerical Data

Capacity Between Group 1 Components and	Equivalent Plate Area in^2	Spacing and Dielectric	Calculated Capacity (Pico Farads)	Total Capacity (Pica Farads)
Cluster #1 Center Canister	fuses: 2	RTV-60: 0.3" Surlyn: 0.125" Air: 0.458"	0.76	0.76
	large jct. block: 0.45	Surlyn: 0.125" Air: 0.458"	0.2	0.2
Side Canisters	fuses: 0.99	RTV-60 Total: Surlyn 0.81"	0.825	1.65
	large jct. block: 0.278	Surlyn: 0.158"	0.95	1.9
Cluster #2 Center Canister	fuses: 2.2	RTV-60: 0.3" Surlyn: 0.125" Air: 0.458"	0.835	0.835
Side Canister	fuses: 1.1	RTV-60: 0.3" Surlyn: 0.81"	0.92	1.84
Cluster #3 Center Canister	fuses: 1.21	RTV-60: 0.3" Surlyn: 0.125" Air: 0.458"	0.46	0.46
	small jct. block: 0.3	Surlyn: 0.125" Air: 0.458"	0.133	0.133
Side Canisters	fuses: 0.605	RTV-60 Total: Surlyn 0.81"	0.50	1.0
	small jct. block: 0.21	Surlyn: 1.0"	1.113	0.226
Cluster #4 Center Canister	fuses: 0.55	RTV-60: 0.3" Surlyn: 0.125" Air: 0.458"	0.21	0.21
Side Canisters	fuses: 0.275	RTV-60 Total: Surlyn 0.81"	0.226	0.452

2.3.4.2.2.3 Capacitance C_2

The capacitance C_2 (and C_3, also) will be a function of the physical surroundings of the XM 165 assembly. For example, if the assembly is resting on a conductive (metal) ground plane the capacity C_2 will be larger than if the unit were resting on an insulator or suspended from a support, such as when installed on an aircraft. Both capacitances C_2 and C_3 will be calculated in the present case assuming the assembly to be resting on a conductive ground plane.

2.3.4.2.2.3.1 Capacity Between Canisters.

The metal canisters in each cluster shell assembly form a matrix of capacitances. This capacitive matrix would be very difficult to represent completely by a mathematical expression. However, because of the close spacing of the canisters in the assembly the largest portion of the capacity between any two adjacent units is reasonably well concentrated in the region of closest proximity and representation of the assembly by a matrix of lumped capacitors is therefore appropriate. The capacity between two cylinders whose axes are parallel and whose diameters are equal is given by the following expression (Doc. 58, Section 8):

$$C = \frac{\epsilon_r \times 10^{-9}}{36 \cosh^{-1}(D/2a)} \quad \text{Farads/meter}$$

where

ϵ_r is the relative dielectric constant of the medium separating the cylinders

D is the center-to-center spacing of the cylinders.

a is the radius of the cylinders

For the present case, D = 1.275", 2a = 1.259" (filled canister), $\epsilon_r = 1$ (for air) and the length of the canisters is 2.5". Substituting these numerical values into the above equation gives,

$$C = \frac{1 \times 10^{-9}}{36 \cosh^{-1}(1.275/1.259)} \cdot \frac{2.5}{39.37} \quad \text{Farads}$$

$$C = \frac{2500}{(36)\ (0.16)\ (39.37)} \quad \text{pF} = 11 \text{ pF}$$

This value of capacity is that between two isolated cylinders, but because of the relatively close spacing of the canisters this value should be reasonably accurate as the capacity between adjacent canisters. The capacitor array can be visualized by assuming an 11 pF capacitor connected between each adjacent pair of the 0.322" diameter holes shown on the cluster pusher plate drawing, E14-23-1909.

2.3.4.2.2.3.2 Capacity Between Group 1 Components and the Canisters.

Before attempting to solve for the equivalent capacity between any two terminals of the capacitive array, the capacity between the canister array and the Group 1 components and between the canister array and the ground plane will be determined. If these two capacitances are sufficiently small compared to the nominal equivalent capacity of the array then it will not be necessary to obtain a very accurate value for the latter.

The capacity of the Group 1 components to the canister arrays involves the first four cluster shell assemblies. The capacity to each of the four canister arrays will be different as the arrangement of the Group 1 components (junction blocks and fuses) above each is different as shown by the following list. The portion of the Group 1 component listed for each cluster shell assembly is that portion located in the 2.5 inch section corresponding to the location of the canisters in that cluster assembly, as follows:

Cluster	Corresponding Group 1 Components
1	10 fuse sections 1.8" in length; large junction block
2	8 fuse sections 2.5" in length
3	4 fuse sections 2.5" in length + 2 fuse sections 0.5" in length; small junction block
4	2 fuse sections 2.5" in length

The various Group 1 components have capacity to several of the canisters at the top of the cluster assembly. The capacity of the three nearest canisters only will be determined as the capacity to other canisters will be negligibly small. The capacities to the two canisters on either side of center will be assumed to be equal because of their symmetrical location. The capacities will be calculated by assuming the cylindrical surface of the canisters to be equivalent to a plane area equal to the area of the Group 1 components and located at the closest spacing to the canisters. This approach simplifies the calculation and compensates partially for the larger curved surface of the cylinder.

The numerical data used to calculate the various components of the capacity C_2 are listed in Table 2-1 as are the calculated values of capacity.

2.3.4.2.2.3.3 Capacity Between Canisters and Ground Planes.

The capacity between the bottom row of canisters in each cluster and the ground plane upon which the XM165 is assumed to be resting will be the same for each cluster except the end clusters which will have capacity also from one end to the ground plane. This latter component of capacity will be small compared to the formed component and will be neglected as will the capacity between the ends of adjacent clusters of canisters.

The canister located at the bottom center of the cluster is spaced approximately 0.25" from the ground plane, half the spacing being the surlyn shell material and the other half air. The aluminum canisters in the bottom layer are spaced 0.637" vertically and 1.104" horizontally in each direction from the bottom center unit. The capacity between a canister and the ground plane is just double the capacity between a pair of canisters spaced twice as far apart. Thus, the equation for the capacity between two cylinders used previously can also be applied here. The center-to-center spacing, D, is just twice the distance from the canister center to the ground plane. The situation is complicated by the presence of two different dielectric materials (air and surlyn) in the space between the cylinder and ground plane. Because the spacing appears implicitly in the equation just referred to, the easiest approach is to convert the spacing to an equivalent air spacing before calculating the capacity. The calculation of the capacity between the bottom center canister and the ground plane is:

$$\text{Equivalent air spacing} = 0.125'' \text{ (air)} + \frac{0.125'' \text{ (Surlyn)}}{2.4}$$

$$= 0.177''$$

$$a = \text{radius of canister} = 0.630''$$

$$D = 2a + 2d = 2(0.630) + 2\,(0.177) = 1.61''$$

$$C_{CG} = \frac{2\epsilon_r \times 10^{-9}}{36 \cosh^{-1}(D/2a)} \quad \text{Farads/m.}$$

$$C_{CG} = \frac{2 \times 10^{-9}}{36 \cosh^{-1}\left(\frac{1.61}{1.26}\right)} \cdot \frac{2.5}{39.37} \quad \text{F.}$$

$$C_{CG} = \frac{5000}{36(0.73)\,(39.37)} \quad \text{pF} = 4.8 \text{ pF}$$

The capacity between each of the three canisters on each side of the center one and the ground plane was calculated and is as follows:

- $C_{1G} = 2.4$ pF
- $C_{2G} = 1.9$ pF
- $C_{3G} = 1.65$ pF

All of the components of the capacity C_2, between the Group 1 components and the ground plane, are now known. However, determining the value of C_2 from the values of its components is not readily accomplished. The difficulty in determining C_2 is principally due to the complexity of the array of cluster shell assembly. The capacitor array representing the component of C_2

corresponding to each cluster shell assembly is shown in Figure 2-5. The other components of C_2 are also included in the schematic diagram. The small circles in the diagram represent the canisters.

One approach to obtaining an approximate equivalent value for the array of capacitors representing the capacity between pairs of canisters is to view the arrays as (vertical) branches consisting of 4 and 5 capacitors in series with adjacent branches being coupled via additional capacitors. The effect of the coupling capacitors is to equalize the voltage division across the series strings of capacitors so that the array of capacitors behaves more like a single capacitor. This suggests representing the entire array as a single capacitor which implies that the capacitances between the Group 1 components and the canister array are effectively in parallel, as are the capacitances between the canister array and the ground plane.

The equivalent canister array capacitance will be assumed to be equal to the parallel combination of seven branches, each branch consisting of four capacitors in series. The value of the individual capacitors was previously determined to be 11 pF, so the equivalent capacity of the array is

$$C_A = \frac{7(11)}{4} = 19.25 \text{ pF}$$

The procedure for finding the value of C_2 is to calculate the equivalent capacity between the Group 1 components and the ground plane for each of the four cluster shell assemblies and sum the four resulting values. The equivalent capacity for a cluster is

$$C_{CL} = \frac{1}{\frac{1}{C_{G1-A}} + \frac{1}{C_A} + \frac{1}{C_{G-A}}}$$

C_{G1-A} is the total capacity from the Group 1 components to the canister array, obtained from Table 2-1.

C_A is the equivalent capacity of the canister array, just determined (= 19.25 pF for each cluster shell assembly)

C_{G-A} is the equivalent capacity from the canister array to the ground plane $C_{G-A} = C_{CG} + 2C_{1G} + 2C_{2G} + 2C_{3G} = 4.8 + 2\,(2.4) + 2(1.9) + 2\,(1.65) =$ 16.7 pF for all shell assemblies.

The components of capacity C_2 are tabulated below and its value determined.

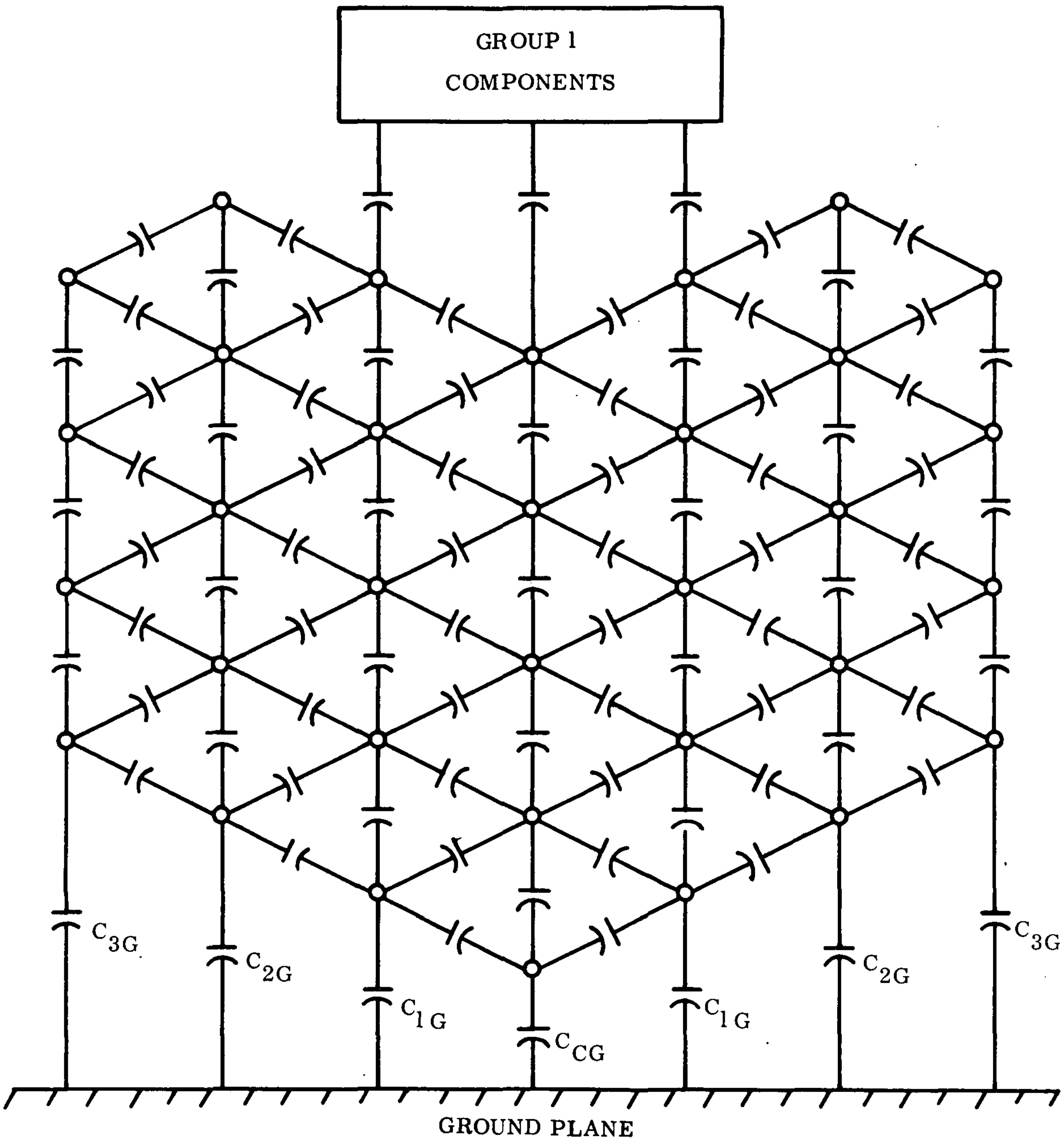


Figure 2-5. Equivalent Capacitor Array for a Cluster Shell Assembly

Cluster No.	C_{G1-A} pF	C_A pF	C_{G-A} pF	$C_{eq.}$ pF
1	4.51	19.25	16.7	3.0
2	2.68	19.25	16.7	2.06
3	1.82	19.25	16.7	1.51
4	0.66	19.25	16.7	0.615

Total (C_2) = 7.185 pF,

say 7.2 pF

In view of the several assumptions and simplifications made during the determination of this value of C_2, it must be realized that it is not an accurate value, but rather a representative one.

2.3.4.2.2.4 Capacitance C_3

The capacitance C_3, between the Group 2 components and the ground plane will not be greatly different from the value of C_2 just determined. C_3 will be larger than C_2 as the adapter, junction blocks, fuses and other right side components are all joined electrically. However, the strongback is screened from the canisters by the fuses and junction blocks and is further from the canisters than are those components. The slight difference in value between C_2 and C_3 and the resultant slight effect on the transient behavior of the equivalent circuit does not warrant the rather extensive effort which would be required to obtain a more accurate value for C_3. This judgment is further justified when the limited accuracy of the capacity calculations is considered.

2.3.4.2.3 Equivalent Circuit

The equivalent electrical circuit of the XM15 canister cluster is shown in schematic form in Figure 2-6.

The calculated values for the capacitances C_1 and C_2 indicate that less than one-fourth of any transient voltage appearing on C_3 would be developed on C_1 as it is more than three times as large as C_2. However, it should be remembered that the calculation of C_1 was based upon the assumption that the RTV-60 silicone rubber impregnant filled the spaces between the time delay and igniter fuses and the small junction block. If these spaces contained air instead of RTV-60 the calculated value of C_1 would be 9.9 pF instead of 23.5 pF and the voltage division between C_1 and C_2 would change drastically.

No calculation of the resistances R_{12} and R_{13} which shunt C_2 and C_3 in the equivalent circuit was attempted. The long effective path length of the surlyn material in the cluster assemblies

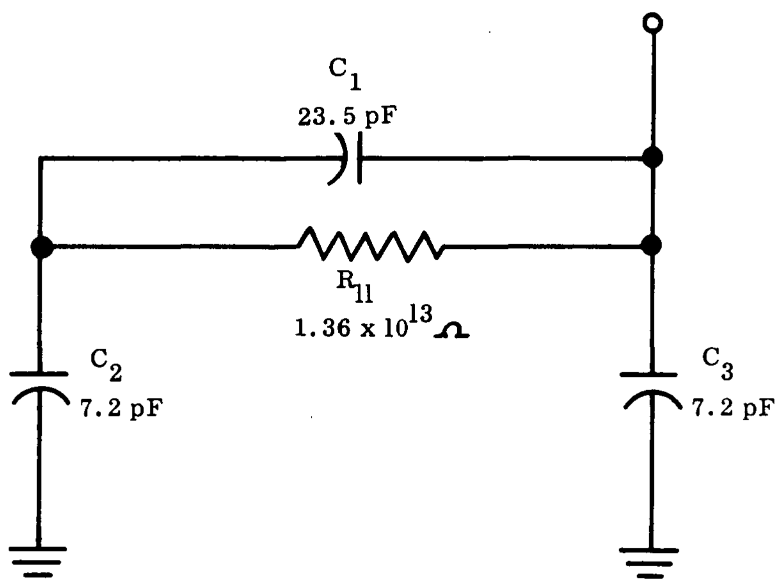


Figure 2-6. Equivalent Electrical Circuit of XM15 Canister Cluster

between the ground plane and the Group 1 and Group 2 components would produce very large values for these resistances. In any event, they would have negligible effect on the transient voltage division between branches 1 and 2.

It should be noted that the values calculated for the equivalent circuit of Figure 2-6 are for one XM15 canister cluster. Equivalent circuit values for the XM165 cluster assembly, which contains two XM15 assemblies are obtained by doubling the capacity values and halving the resistance value.

SECTION 3
SPARK IGNITION SENSITIVITY

3.1 GENERAL

An obvious conclusion concerning the electrostatic problems associated with pyrotechnic materials is that sparking and the resultant heat are responsible for ignition of the material. The spark ignition sensitivity tests should answer the question that arises from this conclusion of weather or not an energy threshold exists which governs the susceptibility of a material to ignition by electrostatic sparking.

A sample or an assembly was placed in a test fixture and subjected to sparks of various energy levels until ignition was obtained or until it became obvious that the material was insensitive. Careful observations were made to determine the exact cause of ignition and to identify the "weak points" in the fusing system.

Based on these test results, recommendations have been made for design changes to reduce or eliminate the premature ignition hazard.

3.2 APPROACH

This test series was not planned to explain the energy source for production of the spark, but rather, given the conditions which would induce a discharge at a particular location, to determine the minimum energy which would induce initiation. Thus an external energy source was used to discharge across artificially imposed electrodes at the location of interest. This concept is schematically displayed in Figure 3-1. Note that the energy stored in the capacitor before discharge is $1/2\ CV^2$, where V is the voltage across the capacitor and C is its capacitance. (If V is measured in volts and C in farads, then the energy is in joules.) Upon discharge most of that energy is expended in the spark between the two electrodes. Plots of the energy versus voltage for various values of capacitance are included in Attachment A to Section 3.

Part of the actual spark discharge apparatus during discharge is presented in Figure 3-2. Figure 3-3 shows the laboratory during testing.

The minimum spark energy to induce ignition is established by a series of discharges which begin at a subcritical level and continue with increasing energy until ignition occurs. This technique brackets the ignition sensitivity between the last previous (noninitiating) discharge and the finial (initiating) discharge. The format for presentation of these data for each configuration is presented in this report as [next energy level below ignition - ignition energy]; e.g., [2.5 - 3.125 joules]. The detailed test procedure is given in Attachment B to Section 3.

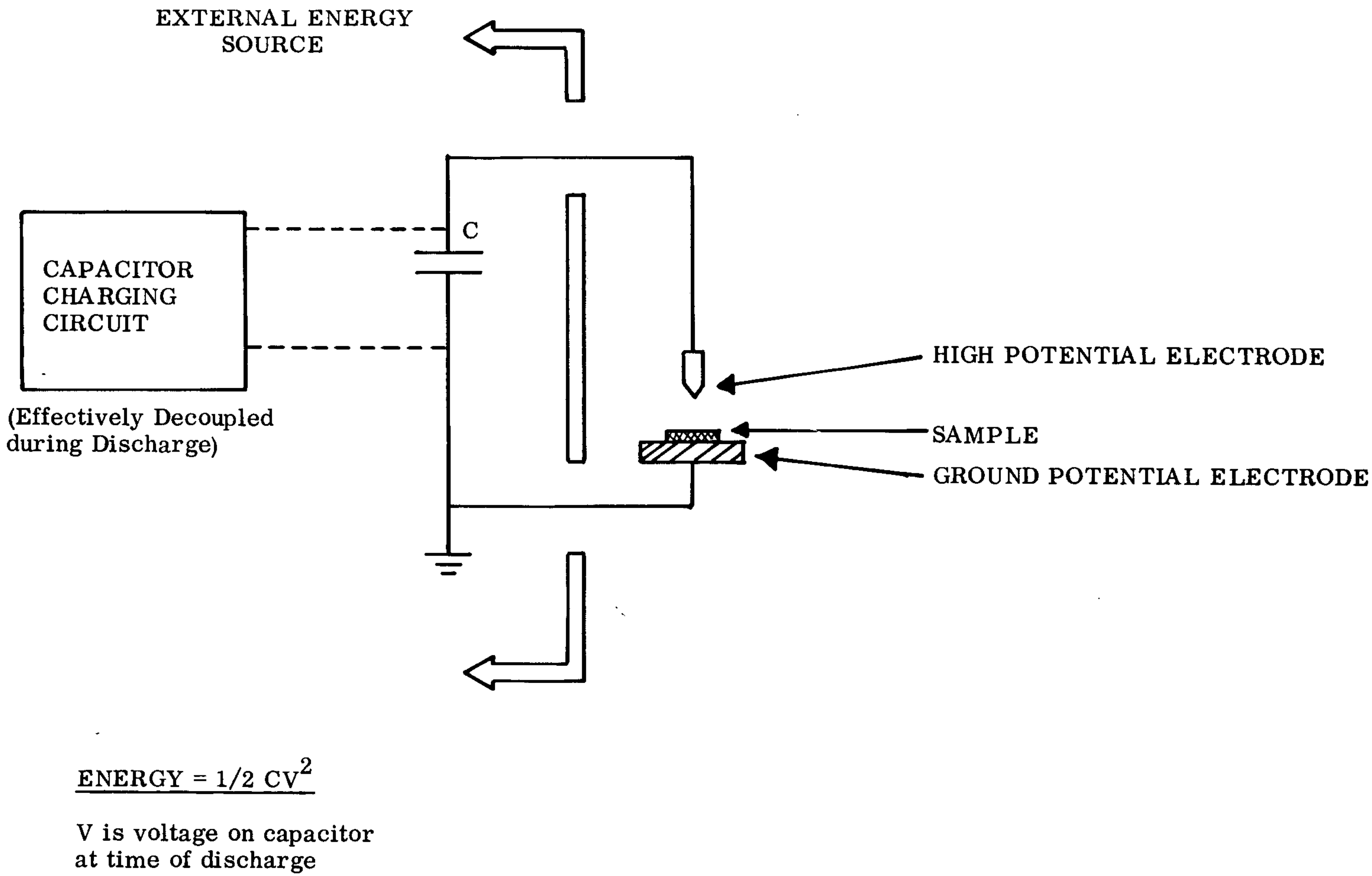


Figure 3-1. Schematic of Spark Ignition Sensitivity Circuit

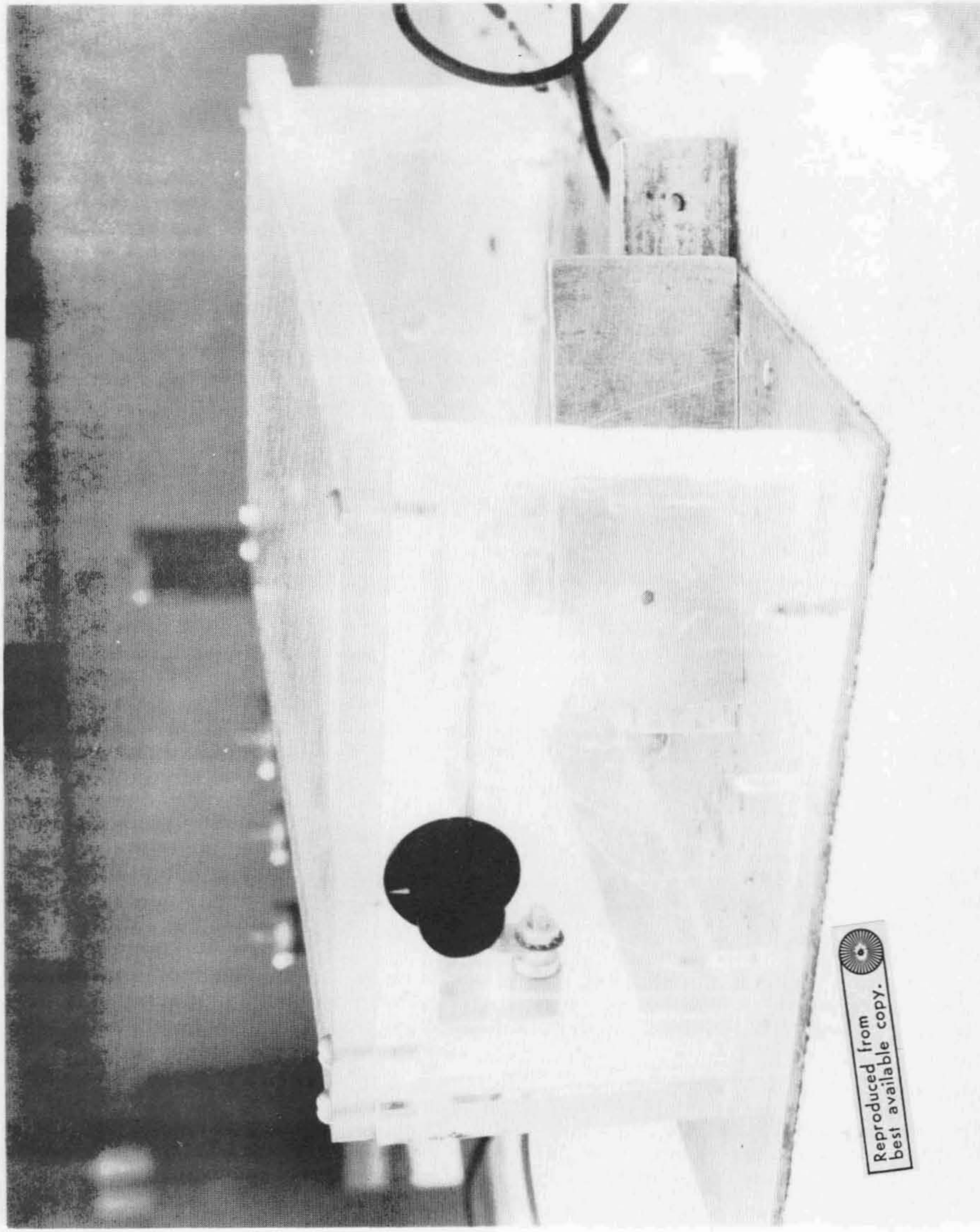


Figure 3-2. Electrostatic Spark Test Fixture - Delay Fuse

Figure 3-3. Electrostatics Laboratory

The sparks from previous discharges will have affected the material along the discharge path, thus preconditioning the material's ignition sensitivity. The magnitude of such synergistic effects will not be established by such a test. In some cases this effect is eliminated by presenting a new portion of the sample to each discharge.

3.3 COMPONENT SELECTION CRITERIA

The XM15/XM165 clusters and E8 launcher systems are described in paragraphs 1.2 and 1.3, respectively, of the Phase I report. The major components of the XM15 fuse train are shown in Figure 3-4, and those of the E8 system in Figure 3-5. The pyrotechnic materials in the fuse trains are the pellets in the junction blocks and the reactive components of the delay lines and the line igniter. Determination of the ignition sensitivity of these materials, of the materials in their normal environment, of the junctions of two or more components, of two or more components in series, and of the complete system will establish as well as possible the location and magnitude of the minimum ignition energy (weakest link) of the XM15 fuse train. The configurations tested are listed in Table 3-1.

During manufacture of the XM15 fuse train the assembled fuse train is encapsulated in RTV-60. The RTV can then seep into cracks between the fuse and junction block, possibly providing an insulating layer between the two components. This condition provides a potential ignition source via electrostatic discharge (as discussed in paragraph 2.2). Thus special tests were performed to study this situation and to test recommended modifications to improve the electrical contact at junctions. Other special tests were performed to verify the feasibility and effectiveness of other recommendations as the tests proceeded.

3.4 ELECTROSTATIC SENSITIVITY OF THE XM15 FUSE TRAIN

3.4.1 GENERAL

Following the test selection rationale of paragraph 3.3, the list of components for testing given in Table 3-1 was developed. A few representative components were subjected to preliminary tests at an outside test range to establish the safety precautions required for the primary tests. The preliminary tests and the test criteria which was established as a result of these tests are presented in Attachment C to this section. These results were incorporated into the test procedure given in Attachment B.

Individual tests are discussed in subsequent sections. The raw data for all tests is included in Attachment D to this section.

3.4.2 MATERIAL AND COMPONENTS TESTS

3.4.2.1 Test Results

Table 3-1. Spark Ignition Sensitivity Tests

		MATERIALS	COMPONENTS	JUNCTIONS	SUBASSEMBLIES	MAJOR ASSEMBLIES
XM15/XM165	Normal Configuration	Pellet (3.4.2.1.3) Lead Azide (3.4.2.1.1) Delay Fuse Material (3.4.2.1.2)	Line Igniter (3.4.2.1.1) Delay Fuse (3.4.2.1.2) Pellet - Junction Block	Pellet - Junction Block (3.4.5.2.1.2 with fuse installed 3.4.5.2.1.3) Pellet - Junction Block with fuses installed encased in RTV (3.4.5.2.3.3)	One Junction Block with fuses installed encased in RTV (3.4.5.2.3.4) with fuel lines shunted by second junction block Complete assembly, including 2 junction blocks, encased in RTV (3.4.5.2.3.5) Complete assembly, including 3 junction blocks, encased in RTV (3.4.5.2.3.6) (3rd inert and shunting fuse lines)	
	Special Studies		Effect of coated pellet in junction block Coating Material: Parafin (3.4.3.2.1) Aluminum Paint (3.4.3.2.2) Nitrocellulose (3.4.3.2.3) Comparison of Aluminum and Lexan Junction blocks (3.4.5.2.1)	Effect of injecting RTV and RTV primer in crack between junction block and fuse (3.4.5.2.3.1, 3.4.5.2.3.2) Comparison of junctions with and without conductive cement applied (3.4.5.2.2)		Complete XM15 Fuse train with modification to reduce electrostatic ignition sensitivity. Units manufactured by Thiokol Chemical and Brunswick Corps. (5.2)
E8		Fuse strip (3.3.2.1) Thermolite (3.3.2.2)	Fuse strip (3.3.2) Thermolite Igniter (3.3.2.2) Squib (3.3.2.3)		Distribution fuse subsystem (3.3.3.1) Primer fuse subsystem (3.3.3.2)	

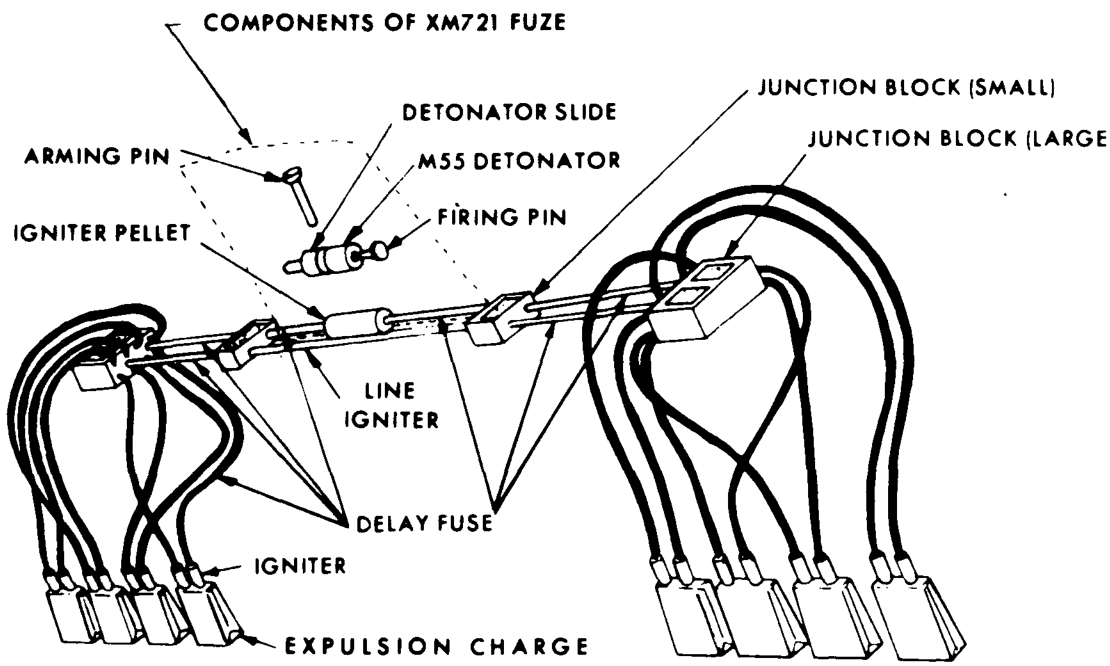
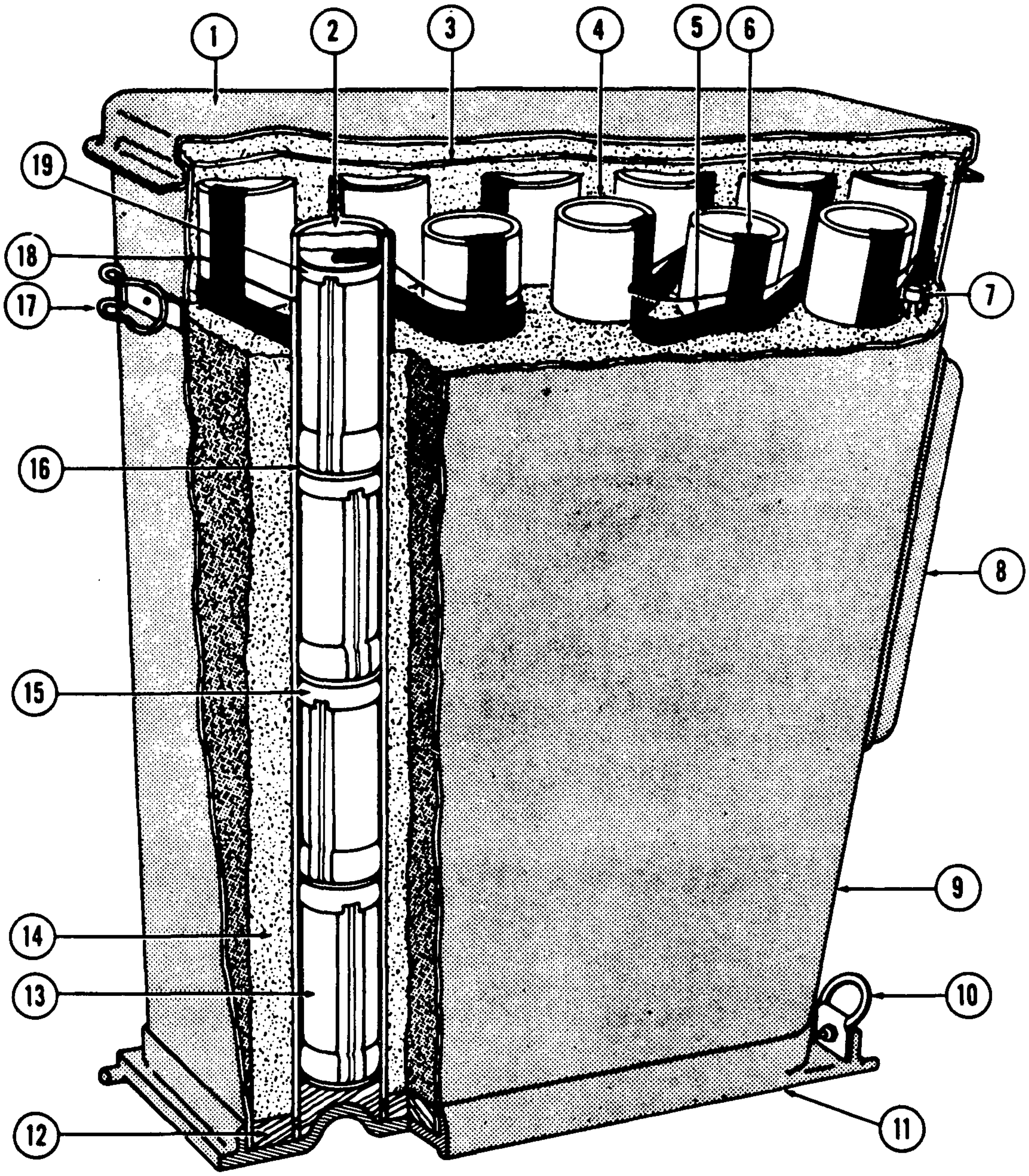


Figure 3-4. XM15 Cluster Fusing System



1	Top cover	11	Baseplate
2	Foam cap	12	Epoxy resin
3	Foil vapor barrier	13	E23 cartridge
4	Paper tube	14	Polyurethane foam
5	Main fuse train	15	Plastic separator cap
6	Fuse strip	16	Cardboard separator disc
7	Electrical squib	17	Trail release catch
8	Firing well cover	18	Auxiliary fuse train
9	Plastic case	19	Plastic separator cap, flanged
10	Carrying harness attachment ring		

Figure 3-5. Launcher Module - Cutaway View

3.4.2.1.1 Lead Azide

A series of tests was conducted on the lead azide fuse line. The one-half inch length sample was placed on a grounded aluminum block and subjected to electrostatic spark discharges of various energy levels. These arcs were allowed to discharge at the center of the specimen and at the ends. Energy levels as high as 50 joules were allowed to dissipate through the lead azide fuse with no ignition.

Subsequent conversations with the manufacturer revealed that lead azide fuse lines have been subjected to as much as 50 kv during factory tests with no ignition. However, with a pinpoint probe centered exactly at the cross-section end of the lead azide, .0002 joules can cause ignition, but ignition does not occur if the probe is slightly off center.

3.4.2.1.2 Delay Fuse

A series of tests similar to that run on the lead azide was conducted on the delay fuse. One - inch lengths of the fuse were subjected to electrostatic arcs of various energy levels.

The delay fuse is not manufactured such that the core is always symmertical about the lontitudinal axis of the fuse. It was observed during testing that, if the fuse specimen was oriented so that during discharge the arc went to the thin wall of the lead sheath, the fuse would ignite. Consistent ignition through the lead sheath was observed in the energy range of 10 to 50 joules.

Additional tests were run with the arc allowed to strike at the end of the fuse sample. The powder core was exposed, and the discharge point was centered above the core. Results of these tests showed consistent ignition of the fuse core at energy levels of 10 to 20 microjoules. These extremely low energy levels indicate the sensitivity of the fuse core material.

3.4.2.1.3 Ignition Pellet

Again using the test procedure presented in Attachment B to this section, a series of tests was conducted on the junction block ignition pellets. A whole pellet was placed on a grounded aluminum block and subjected to electrostatic arcs of various energy levels which were allowed to discharge directly to the surface of the pellet.

It was discovered that energy levels of approximately .01 joules were adequate to ignite the pellets. Arcs occurred below this energy level with no apparent effects. A particularly interesting observation was that one pellet which had been tried at as high as 7 kv ignited at 3 kv volts after being repositioned to allow arcing to pass through at its largest dimension. It is theorized that energy which would have normally been dissipated in the air gap was dissipated in the pellet, causing ignition at the lower levels.

In any event, it was determined that the energy levels required for igniting the pellet are very low.

3.4.2.2 Preliminary Discussion

Based on the results of the tests described in paragraph 3.4.2.1, it is concluded that:

- The lead azide fuse is, for all practical purposes, insensitive to electrostatic ignition.
- The lead sheathed delay fuse is relatively insensitive to arcs at the sheath but very sensitive to arcs at the ends where core powder is exposed.
- The ignition pellets are very sensitive to electrostatic arcs, and every effort should be made to shield the pellet with a conductive casing such as a metallic junction block.
- The aluminum junction blocks are far superior to the lexan from the standpoint of preventing premature ignition of the fuse train.
- Nonconductive cements or glues used to hold the fuse line in the junction block can decrease the sensitivity of the fuse train.

3.4.2.3 Recommendations

Based on the results of the test data and conclusions, the following were recommended to decrease the electrostatic sensitivity of the XM-15 fuse train:

- Provide better surface contact between the fuse line and the junction block by tighter control over machining operations on the junction block or by utilizing conductive cement to hold the fuse lines in place.
- After cutting to the correct length, coat the fuse ends with a thin film of a low - melting-point material to prevent ignition of the core powder by low energy arcs at the ends of the fuse.
- Coat the ignition pellet with a thin film of a low-melting-point material to prevent flaking and dusting and to prevent ignition by low energy, such as those reported in paragraph 3.4.4.2.1.2.

3.4.3 COATED PELLET TESTS

3.4.3.1 General

During previous electrostatic sensitivity testing (paragraph 3.4.2.1.3), it was theorized that flaking and powdering of the XM15 fuse train ignition pellets and delay fuses made the XM15 fuse train more susceptible to electrostatic arcs.

To alleviate this situation, consideration was given to applying a coating to the fuse ends and the pellets. Several readily available materials were selected for test purposes; i.e., parafin, aluminum paint and nitrocellulose were tried. The objective was to check the coating concept only, not to determine or investigate types of coatings.

For this series of tests, a one microfarad discharge capacitor and test voltages from 1 to 10 kv in increments of 1 kv (0.5 to 50 joules) were used. Firon silver lacquer, manufactured by Electro Materials Corporation of America, was used as a fuse bonding material in all tests (delay fuse to aluminum junction block).

3.4.3.2 Test Results

The raw test data is included in Attachment E of Section 3. The results are summarized in Table 3-2.

Table 3-2. Coated Pellet Tests Results

COATING MATERIAL	ENERGY APPLIED	IGNITION	NORMAL IGNITION	REMARKS
Parafin	Up to 50 joules	No	No (Fuse only)	No marks on pellet under normal ignition.
Aluminum Paint	Up to 50 joules	No	No (Fuse only)	No marks on pellet under normal ignition.
Nitrocellulose	Up to 50 joules	No	No (Fuse only)	With normal ignition, the coating on the pellet was scorched.

3.4.3.2.1 Parafin Coating

Commercial grade parafin was melted and applied to a pellet and the ends of the fuses. The pellet was installed in the large junction block and the fuses were bonded in place with the silver lacquer. Arcs with energy levels up to 50 joules were applied to the outer sheath of the delay fuse without ignition.

To check the configuration for normal mode operation, the fuse was deliberately ignited. The fuse burned but it did not ignite the coated pellet.

An arc of 50 joules was applied directly to the coated pellet without ignition occuring.

3.4.3.2.2 Aluminum Paint Coating

An aerosol aluminum paint (Rust-Oleum) was used as a coating material. The fuse, pellet and junction block were configured as for the parafin test. As in the parafin test, up to 50 joules were applied without ignition.

The pellet was removed from the junction block and subjected to direct arcs of 50 joules with no ignition.

3.4.3.2.3 Nitrocellulose Coating

A mixture containing 4 percent mitrocellulose and 96 percent acetone was used to coat another pellet and the ends of the delay fuses. The configuration was the same as in previous tests.

The test voltage, as in previous tests, was increased to 10 kv or 50 joules, again with no ignition.

Once more, to check the configuration for normal mode operation, the fuse was deliberately ignited. The fuse burned but, as was the case with the other coatings, the pellet failed to ignite. However, the pellet was scorched on the surface where the delay fuse made contact. Another test was conducted without coating the delay fuses, but to no avail.

3.4.3.3 Conclusions

Based on the results of the coated pellet tests, it is concluded that:

- Coatings will desensitize pellets to electrostatic arcs, providing the coating materials is not electrostatic sensitive. Whether or not the desensitizing mechanism is that of preventing the pellet from flaking and powdering is a subject for further study and testing. The scope of these tests was to obtain the end results and not to determine the specific mechanisms involved.
- Unless a coating material can be found which will not decrease normal firing reliability, it is not feasible to pursue the coating technique. Additional research and study is required to identify those coating materials which could possibly accomplish the goal of reducing the sensitivity to arcs without decreasing normal firing reliability.
- These tests should be repeated in order to establish whether low ignition sensitivity is a result of coating effects or due to improper storage of the pellets.
- These tests should be repeated in order to establish whether low ignition sensitivity is a result of coating effects or due to use of inherently desensitized (high moisture content) pellets.

3.4.4 JUNCTION TESTS AND SUBASSEMBLY TESTS

3.4.4.1 General

Previous electrostatic spark ignition sensitivity testing of the elements of the XM15 fuse train considered individual components and subsystems exposed to air. The XM15 fuse train, in its operational configuration, is encapsulated in RTV-60 (silicone rubber). Therefore, this series of spark ignition tests was conducted on subsystem configurations encapsulated in RTV-60.

The objectives of this test series were to determine if, during normal assembling, RTV and the primer could insulate the delay fuse from the junction block and to determine the ignition energy levels if a spark is applied to the delay fuse of several subsystem configurations encapsulated in RTV-60. (The raw data are displayed in Attachment E to this section.)

The delay fuse has a diameter of 0.110 + .000, -.005 inches, whereas the holes in the junction blocks have a specified diameter of 0.110 + .005, -.000 inches. If the fuse is located concentric with the hole, a nominal radial clearance of 0.005 inches will exist, assuming that actual dimensions are averages of the tolerances. This clearance will permit the RTV to seep between the delay fuse and the junction block. Thus, it is possible for the RTV to completely insulate the junction block from the delay fuse. The dielectric strength of RTV-60 is 600 volts/mil. Thus a 0.005-inch (5 mils) layer of RTV between the fuse and the block will break down at a voltage of approximately 3000 volts. A spark will occur at breakdown, exposing the delay fuse and pellet to possible ignition. If there is an air gap between the delay fuse and block of 0.005 inches, the breakdown voltage will occur at approximately 1080 volts (20^{o} C and 760 mm Hg).

A blue silicone primer, GE SS-4155, is applied to the elements of the fuse train (per drawing E14-23-1905) prior to applying the RTV. This is a low viscosity liquid and has a tendency to seep into any voids between the fuse and block but would not completely fill all voids.

3.4.4.2 Tests and Results

Tests numbers in the following paragraphs refer to the test numbers on the data sheets in Attachment F to this section.

3.4.4.2.1 Comparison of Aluminum and Lexan Junction Blocks

3.4.4.2.1.1 Configuration No. 1 (Tests 1-24). The first series of tests utilized the lexan junction blocks (see Figures 3-6 and 3-7). A small pellet placed in the smaller lexan junction blocks was taped with aluminum tape, and one-inch lengths of delay fuse were inserted in the two holes on one side of the block (Figure 3-6). One fuse was grounded and the other subjected to a series of electrostatic discharges.

Various arrangements of the pellet within the block, such as spacing between the fuse ends and the pellet, and contact between the fuse ends and the pellet, were tried, with consistent ignition of the subassembly obtained at energy levels in the range of 0.006 to 0.016 joules.

Similarly, the block was arranged with fuses on opposite sides (Figure 3-7), with one fuse grounded and the other subjected to arcs. Again, ignition occurred in the 0.006 - 0.016 joule range.

These energy levels are approximately the same as required to ignite the pellets by themselves. It is theorized that, since the arc occurred inside the junction block, all of the energy is used in the ignition. This accounts for a slightly lower ignition point than that of the pellet alone.

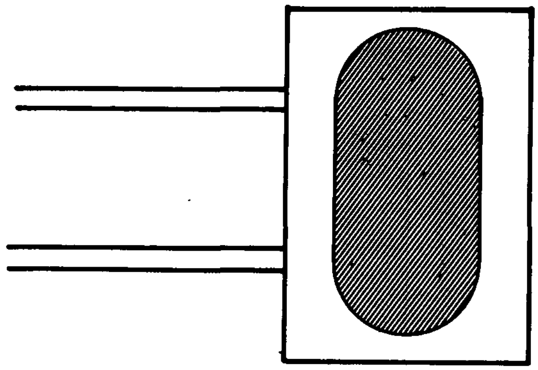


Figure 3-6. Configuration No. 1

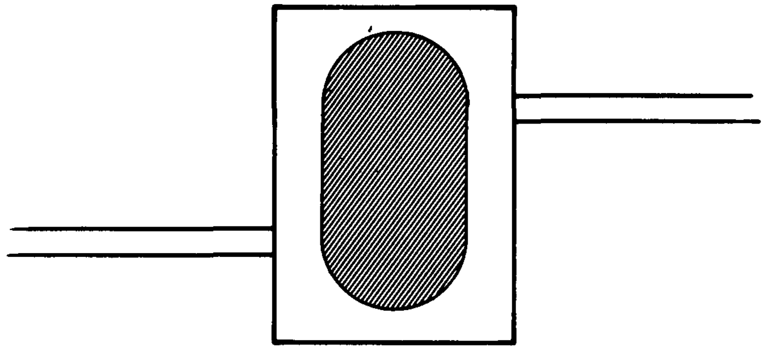


Figure 3-7. Configuration No. 2

2

3.4.4.2.1.2 Configuration No. 2 (Tests 25-69). The second series of tests on subassemblies of the fuse train was conducted with aluminum junction blocks. These blocks, the fuses, and pellets were configured as in Figure 3-7. One fuse was grounded and the other was subjected to a series of electrostatic discharges.

Ignition of the first subassembly in this configuration occurred at approximately 32 joules. Because this level of energy can possibly ignite the fuse through the sheath, dummy fuses of resin core solder were substituted for the next tests in an attempt to isolate the ignition point, and Eastman 910 glue was used to hold the solder in place. Ignition occurred at 4.5 joules, considerably below the first aluminum block test but considerably greater than with the lexan block.

It was theorized that the Eastman 910 acted as an insulator around the dummy fuse line, causing the discharge path to go through the pellet. As a check, the next ignition test used dummy fuses swaged for good fit but not glued. Ignition for this test occurred at 25 joules.

Because the pellet is completely shielded by conductive materials in the aluminum block, it would seem unlikely that the pellet would have ignited even at 25 and 32 joules. It was theorized that tiny sparks occur at the surface areas between the fuse and aluminum block during electrostatic discharge as a result of imperfect contact between the fuse and the aluminum block and could possibly ignite the pellet.

To prove the existence of these "sparks", dummy fuse lines swaged to fit properly were inserted into the aluminum block as in Figure 3-7, except that no pellet was installed. The subassembly was physically isolated from the test fixture with test leads so that the bright arc in the test fixture would not interfere with observing the interior of the junction block. The arc in the test fixture was allowed to strike a test lead connected to one of the dummy fuses. This was repeated many times, with the result that very small but very definite sparks did occur at the interface points between the fuses and the junction block.

3.4.4.2.1.3 Configuration No. 3 (Tests 70-89). A large junction block was configured as shown in Figure 3-8. Live fuses and one pellet were installed; one fuse was grounded and the other subjected to a series of electrostatic discharges. As was found with the small junction blocks, ignition occurred in the range of 1.6 to 4.5 joules.

3.4.4.2.2 Sensitivity of Junctions with Conductive Cement

All tests related to the sensitivity of junctions with conductive cement were conducted on a configuration similar to Figure 3-8. In addition, Firon silver lacquer manufactured by Electro Materials Corporation of America was applied to the fuse-junction block interface.

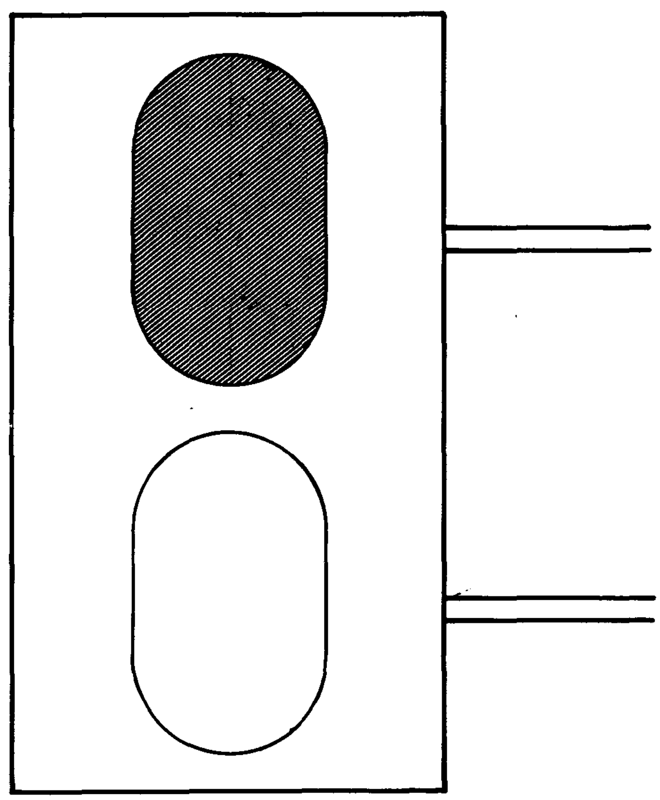


Figure 3-8. Configuration No. 3

3.4.4.2.2.1 Configuration No. 1 (Tests 1-9). Live fuses were bonded to each side of a large aluminum junction block using the silver lacquer material. A pellet was installed in one side and aluminum tape placed over it to hold it in place.

The test voltage was increased incrementally until, at 9 kv or 40.5 joules, ignition occurred. This energy level is considerably higher than was required for ignition in previous tests not utilizing conductive cements.

At this point, it was not known whether ignition occurred as a result of the fuse or the pellet igniting. Previous tests have shown that under certain conditions the fuse can be ignited through the sheath in this energy range.

3.4.4.2.2.2 Configuration No. 2 (Tests 10-18). To isolate the ignition point, dummy fuse lines were installed with the conductive cement. The test procedure was repeated and again ignition occurred at 9 kv or 40.5 joules.

3.4.4.2.2.3 Configuration No. 3 (Tests 19-29). Next, in an attempt to determine a way of desensitizing the fuse and pellet assembly further, dummy fuses were installed with silver lacquer in an aluminum junction block containing a pellet which had been completely coated with silver lacquer.

Again the test procedure was repeated. This time ignition of the pellet failed to occur even at 50 joules.

3.4.4.2.2.4 Configuration No. 4 (Tests 30-39). The dummy fuses were replaced with live fuses. The junction block ends were coated with silver lacquer. The test procedure was repeated, and again the assembly failed to ignite.

3.4.4.2.2.5 Configuration No. 5 (Tests 40-41). The fuse lines were then ignited at the exposed ends to verify normal ignition of the fuse train in this configuration. This time the fuse burned but the pellet did not. Apparently, the silver lacquer material applied to the pellet and the fuse line does not melt rapidly enough to allow the delay fuse to ignite the pellet.

3.4.4.2.3 Studies of Junction Effects on Subassembly Sensitivity

3.4.4.2.3.1 Configuration No. 1 (Tests 56-70). Blue silicone primer, GE SS-4155, was applied to two delay fuse lines and inserted into a large aluminum junction prior to primer curing as shown in Figure 3-9.

When a pellet was installed after the primer cured and sparks were applied to fuse line 1 with fuse line 2 grounded, ignition occurred at [18 - 24.5 joules]. Fuse line 1, from a visual observation, appeared to have ignited prior to the pellet; fuse line 2 did not ignite.

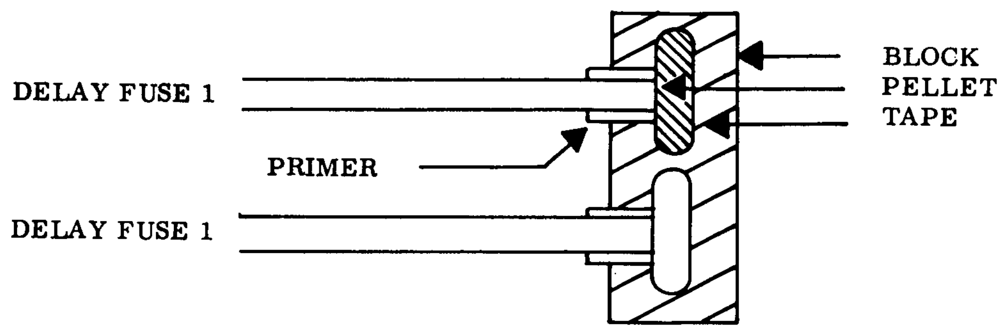


Figure 3-9. Configuration No. 1

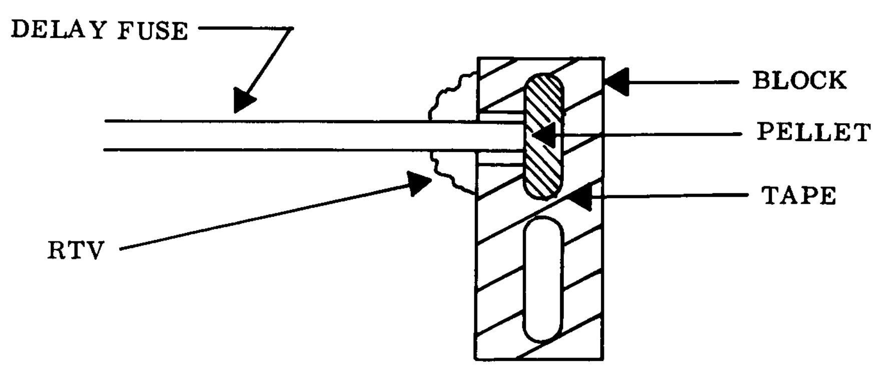


Figure 3-10. Configuration No. 2

3.4.4.2.3.2 Configuration No. 2 (Test 55). RTV-60 was applied to a delay fuse, making sure that the end was not coated. The fuse was then inserted into a large aluminum junction block (before the RTV cured) as shown in Figure 3-10. This assembly procedure provides a worse case test because the RTV is being forced between the fuse and junction block.

When a pellet was installed after the RTV cured and sparks were applied to the delay fuse, with the block grounded, ignition occurred on the first attempt at [0-0.5 joules].

3.4.4.2.3.3 Configuration No. 3 (Tests 51-54). An uncoated delay fuse was inserted into a large aluminum junction block with pellet, and RTV-60 was externally applied as shown in Figure 3-11.

A pellet was installed and sparks were applied to the delay fuse, with the block grounded. Ignition occurred at [2.0 - 3.125 joules].

3.4.4.2.3.4 Configuration No. 4 - Small Junction Block (Tests 48-50). Figure 3-12 shows this test configuration which includes one small aluminum junction block and pellet, delay fuse, lead azide, and one small aluminum junction block without pellet.

Block 1 was assembled with block 2 of test configuration number 2 (see Figure 3-13). Block 2 was added as a shunt and bonded to the delay fuse and lead azide line. Sparks were applied to the center of the lead azide line with ground connected to the center of the delay fuse, and ignition occurred at [2.0 - 4.5 joules].

3.4.4.2.3.5 Configuration No. 5 - Two Small Blocks (Tests 1-7). The delay fuse, lead azide, two small aluminum junction blocks, pellets and aluminum tape were assembled as shown in Figure 3-14. After assembling, SS-4155 blue primer was applied per drawing E14-23-1905. After the primer cured, the unit was potted with RTV-60 (see Figure 3-13).

Sparks were applied to the center of the lead azide line with the center of the delay fuse grounded. Ignition occurred at [2.0 - 3.125 joules]. However, only one pellet and the delay fuse ignited. When the unit was disassembled and thoroughly inspected, no visible evidence was found to account for the misfiring of the other pellet and the lead azide line. An explanation of misfirings during this test series is included in paragraph 3.4.5.3.

3.4.4.2.3.6 Configuration No. 6 - Small and Large Block (Tests 8-47). This test consisted of one large aluminum junction block and pellets, one small aluminum junction block and pellet, one small aluminum junction block, delay fuse, lead azide and aluminum tape configured as shown in Figure 3-15.

Blocks 1 and 2 were assembled as described in test configuration number 5. The two delay fuses from block 1 were bonded to block 2 with silver lacquer to ensure positive electrical contact. Block 3 (without pellet) was added as a shunt to simulate the other half of the fuse train and was bonded with silver lacquer to the delay fuse and lead azide line.

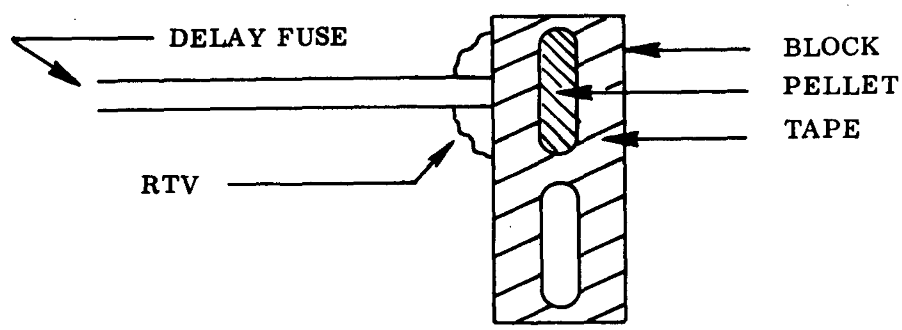


Figure 3-11. Configuration No. 3

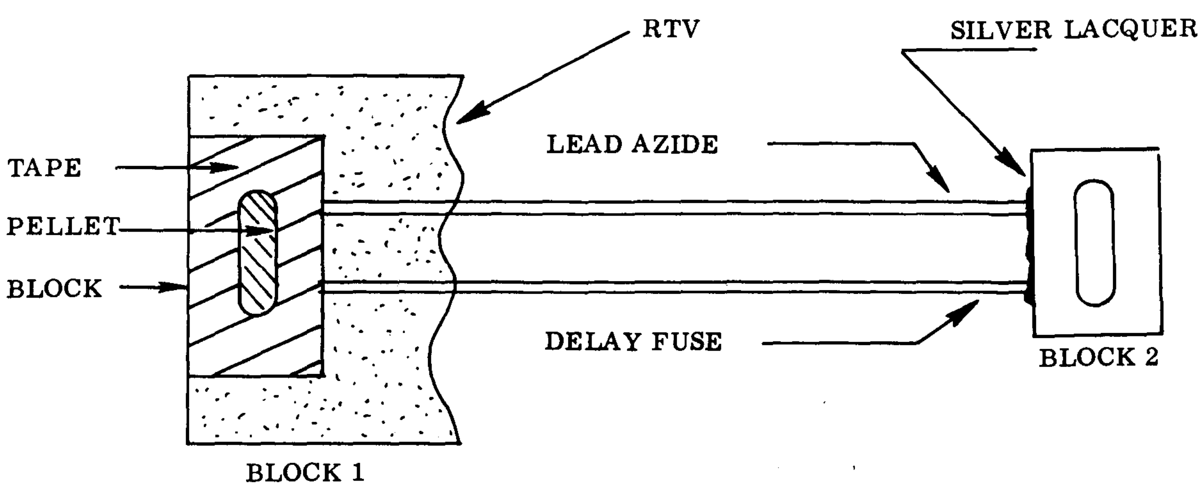


Figure 3-12. Configuration No. 4

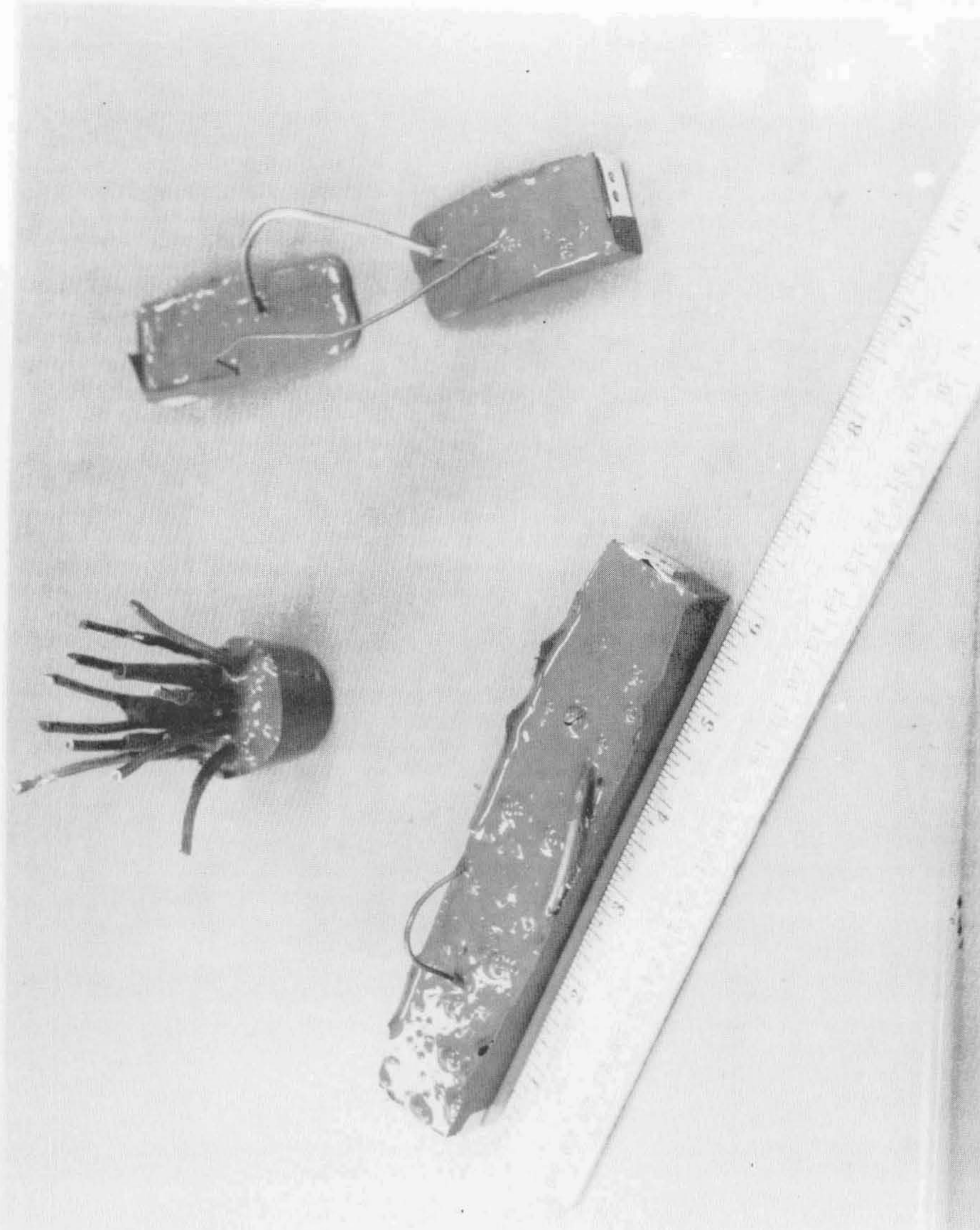


Figure 3-13. Photograph of Various Configurations Tested

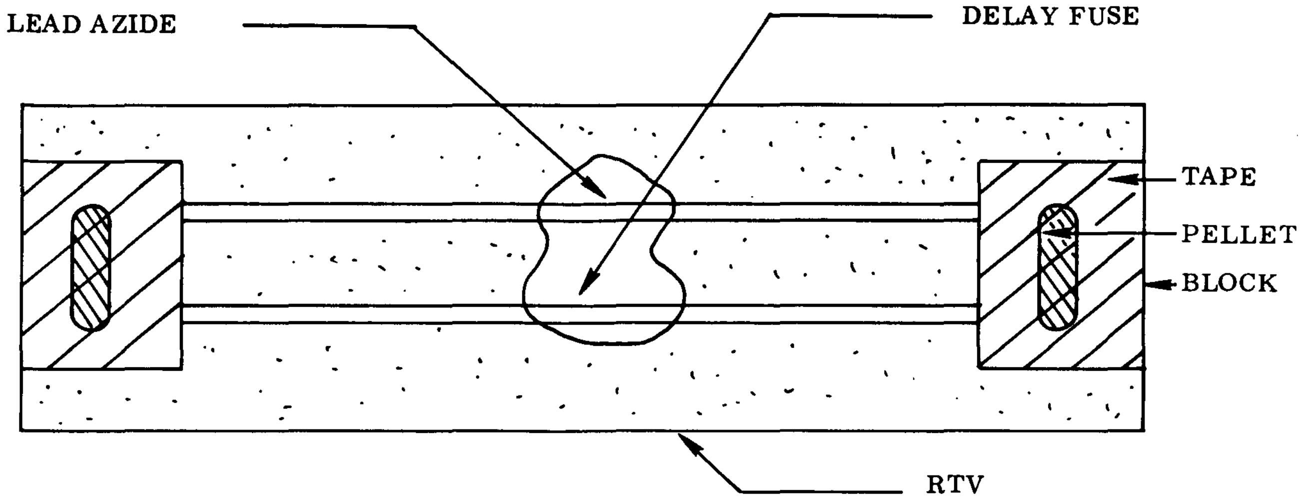


Figure 3-14. Configuration No. 5

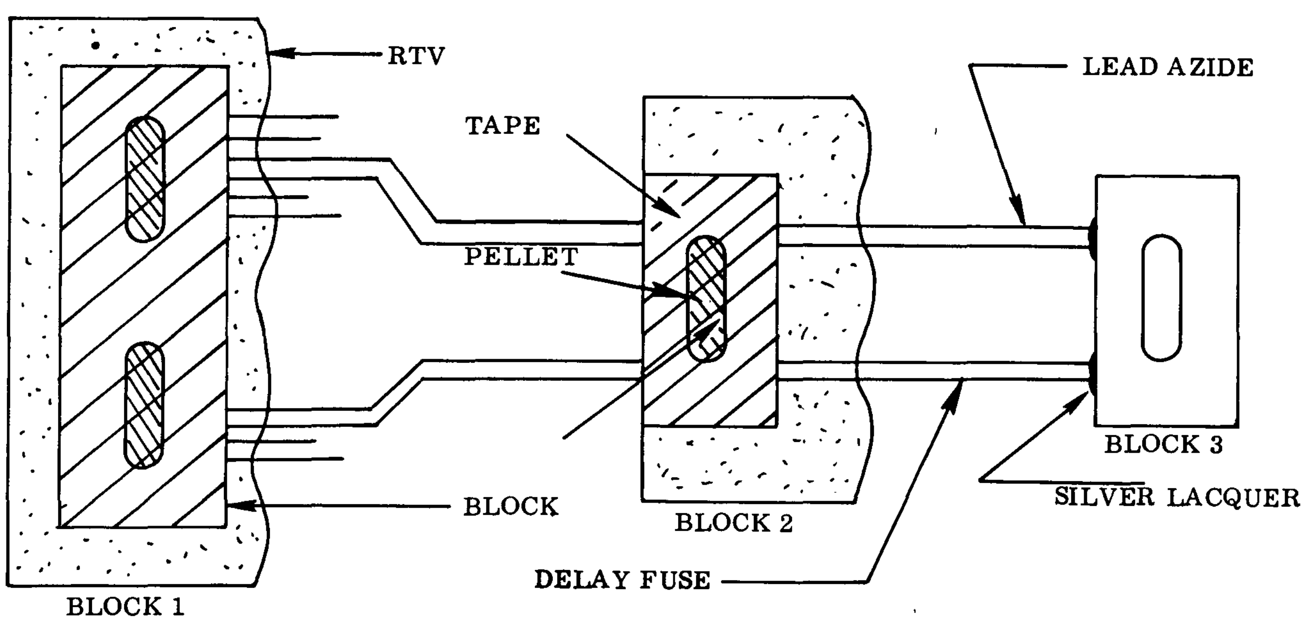


Figure 3-15. Configuration No. 6

To simulate the worse condition for insulator seepage, the primer and RTV were applied to block 1 with the fuse holes oriented vertically. This orientation allows gravity to assist penetration between the fuses and holes in the block.

Sparks were applied to the center of the fuse lines between blocks 1 and 2. One line was grounded and sparks with energies of up to 50 joules were applied without ignition. Then sparking point was moved to the lead azide line and ground was moved to the delay fuse between blocks 2 and 3, with up to 50 joules again applied without ignition.

In order to verify the normal operation of the system, block 3 was removed and the delay fuse into block 2 was ignited. However, the two pellets in block 1 did not ignite. Two of the fuse lines from one of the pellets did ignite, probably from the heat of the input fuse line. When the RTV and aluminum tape were removed from the top of block 1, a small amount of RTV was found between the aluminum tape and the junction block. The pellets were charred and fractured.

During removal of the two large pellets for inspection, they broke apart. From a close visual inspection, it did not appear that either RTV or primer had coated the pellets. It was observed that the pellets were slightly darker than normal, which could indicate a high moisture content.

3.4.4.2.3.7 Test Results. Table 3-3 summarizes the results. Due to a limited supply of material, only one ignition test was conducted for each configuration; therefore, the statistical significance of the data is poor, but it should be considered valid in developing a qualitative description.

Table 3-3. Summary of Junction and Subassembly Tests with RTV-60

CONFIGURATION	IGNITION ENERGY	REMARKS
1. Fuse (with primer applied) inserted in block	18 - 24.5 joules	The delay fuse appeared to have ignited prior to the pellet
2. Fuse (with RTV applied) inserted in block	0 - 0.5 joules	Ignited on first attempt with 1.0 μ f at 1 kv
3. Fuse inserted in block, then RTV applied	2.0 - 3.125 joules	Total ignition
4. 1 block, fuses and pellet encapsulated in RTV	2.0 - 4.5 joules	Total ignition
5. 2 blocks, fuses and pellets encapsulated in RTV	2.0 - 3.125 joules	With normal ignition, the two large pellets did not ignite
6. 3 blocks, fuses and pellets encapsulated in RTV	No ignition up to 50 joules	One pellet and lead azide did not ignite

In configurations 3 through 6 the RTV did, in various degrees, seep into the clearance between the fuse and holes in the junction block as determined by visual inspection. The energy levels for ignition for configurations 3, 4, and 5 were within the same range, 1.6 to 4.5 joules, as previous test (paragraph 3.4) in which the fuse did not make a good electrical contact with the aluminum block.

Configuration 2 indicates that, if RTV completely insulates the fuse from the block, then the ignition energy is low. This follows from the description developed in paragraph 3.4.4.

Depending on the minimum clearance, the breakdown could occur at any voltage below 3 kv. In this test configuration, ignition and voltage breakdown occurred at 1 kv.

Nonignition of the pellets in configurations 1 and 2 may be explained by high moisture content. The pellets, lead azide and delay fuses used in these tests had been stored in a nonenvironmentally-controlled container and were exposed to high humidities for several weeks. The "Assembly Procedure for Canister Cluster Assembly, Chemical Agent, XM165" states "that the pellets are to be stored in a suitably dry, conductive container with desiccant per MIL-D - 3464 and a humidity indicator that will show an excess of 0.20 percent moisture." Zirconium, the fuel in the pellets, in its pure state will, when finely divided, ignite spontaneously in air. However, very high moisture content will increase the ignition level. Other possibilities for nonignition are:

- Improperly manufactured pellet; e.g., the pellet did not contain the correct portions of the zirconium, ferric oxides, etc.
- The primer coated the interface between the delay fuse and pellet.

3.4.4.2.3.8 Conclusions. The conclusions are based on six test configurations with each configuration tested only once. Therefore, test data is not available for statistical analysis.

- RTV and primer will seep between the delay fuse and the junction block during normal manufacturing. Since RTV has a dielectric strength of 600 volts/mil, breakdown and ignition can occur at or below 3 kv. Therefore, the spark ignition sensitivity of the fuse train is increased.
- The use of conductive cement not only electrically bonds the delay fuse to the aluminum block, but, if properly applied, will prevent RTV and primer from seeping between the delay fuse lines and the junction blocks. As shown in previous tests, the use of conductive cement does decrease the spark ignition sensitivity of the fuse train.

ATTACHMENT A
ENERGY GRAPHS

The graphs presented in this attachment represent the energy equation:

$$E = 1/2\,CV^2$$

Where: E = Energy in joules

C = Capacitance in farads

V = The voltage at which the capacitor is charged

Figure 3-A-1 covers the range of 1 to 1000 volts and .000001 to .001 joules.

Figure 3-A-2 covers the range of 100 to 100,000 volts and .001 to 1 joules.

Figure 3-A-3 covers the range of 100 to 100,000 volts and 1 to 1000 joules.

These graphs provide a ready reference for finding the energy if the voltage and capacitance are known.

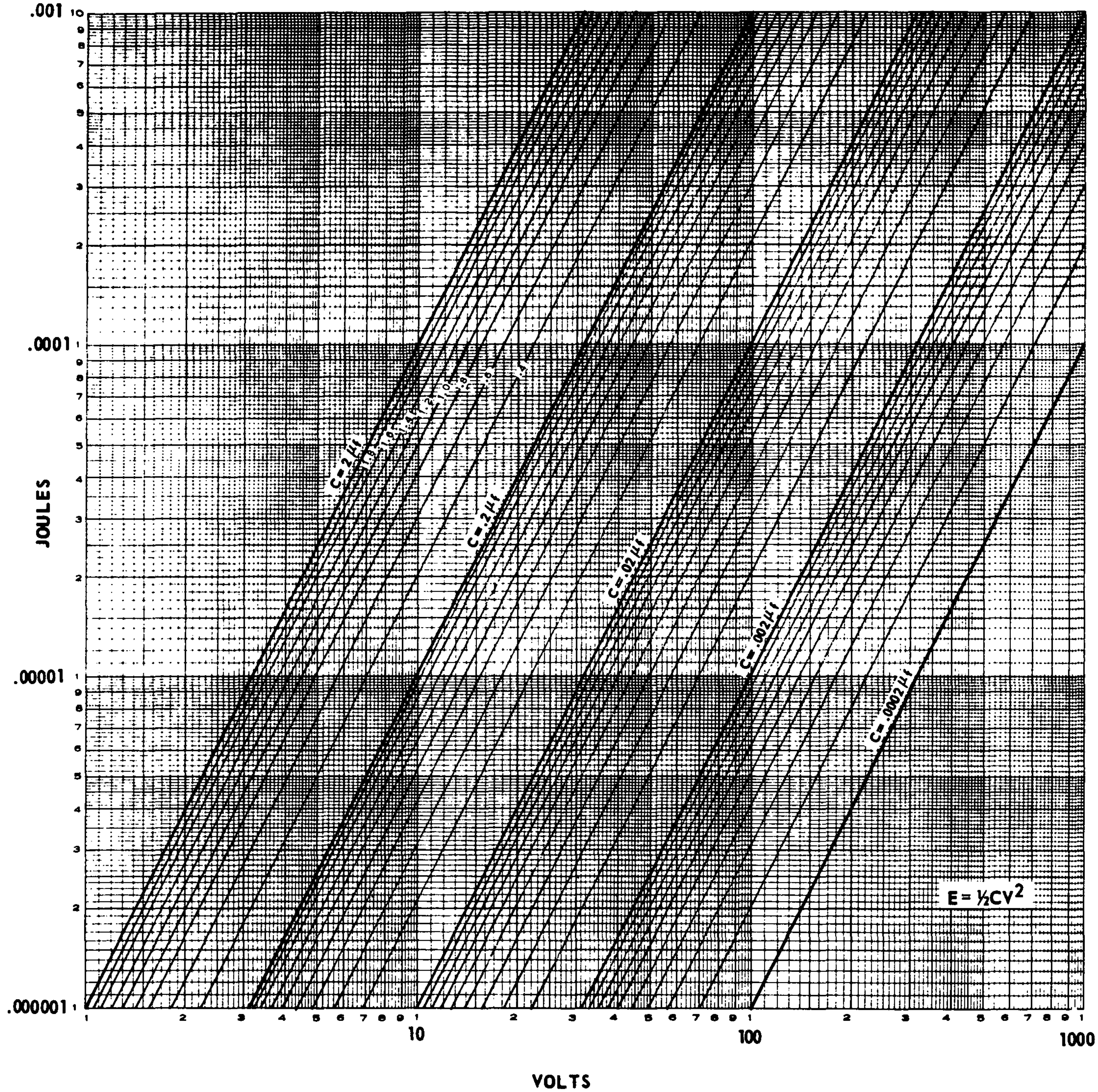


Figure 3-A-1. Plot of $E = 1/2\ CV^2$

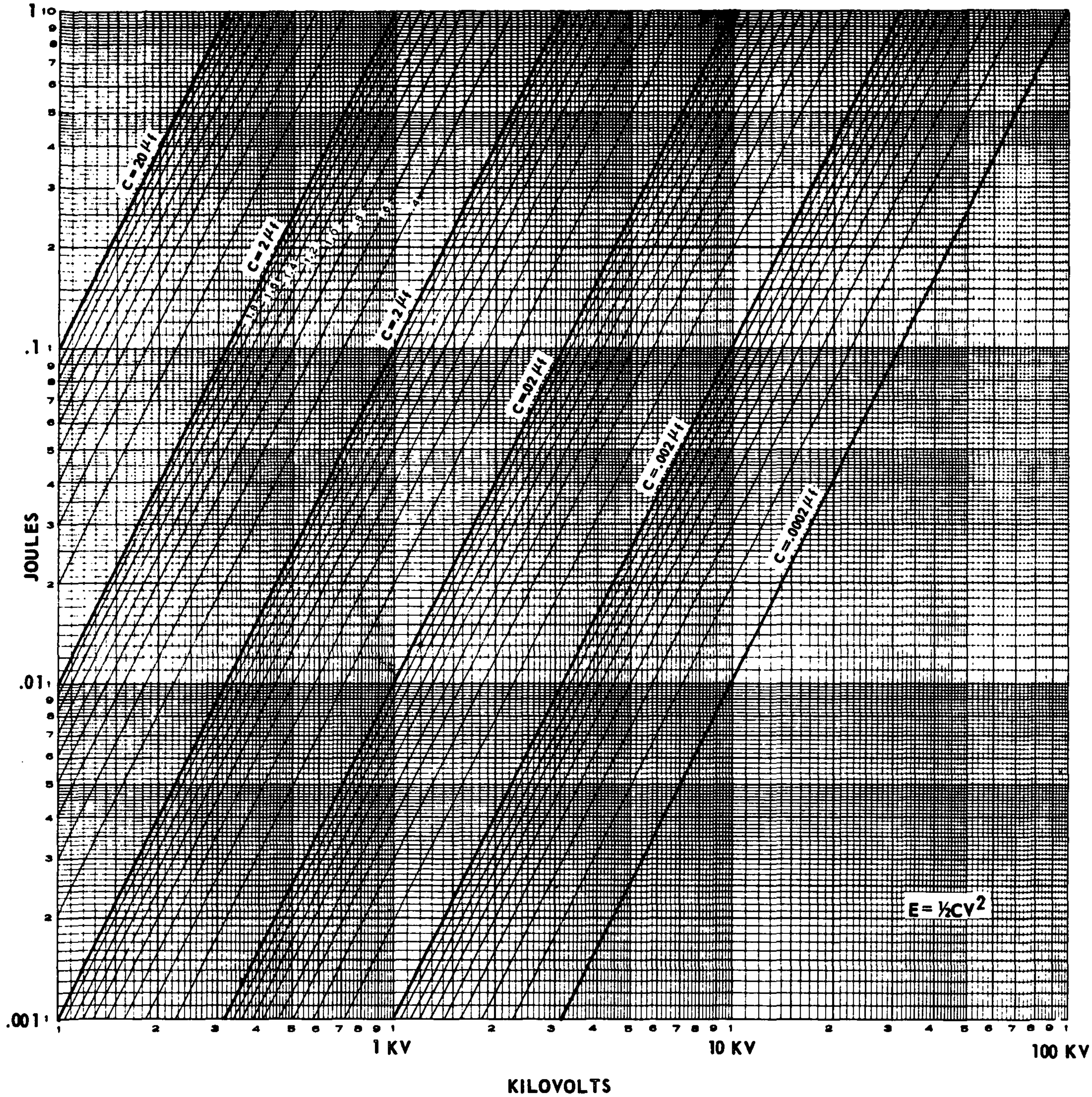


Figure 3-A-2. Plot of $E = 1/2\ CV^2$

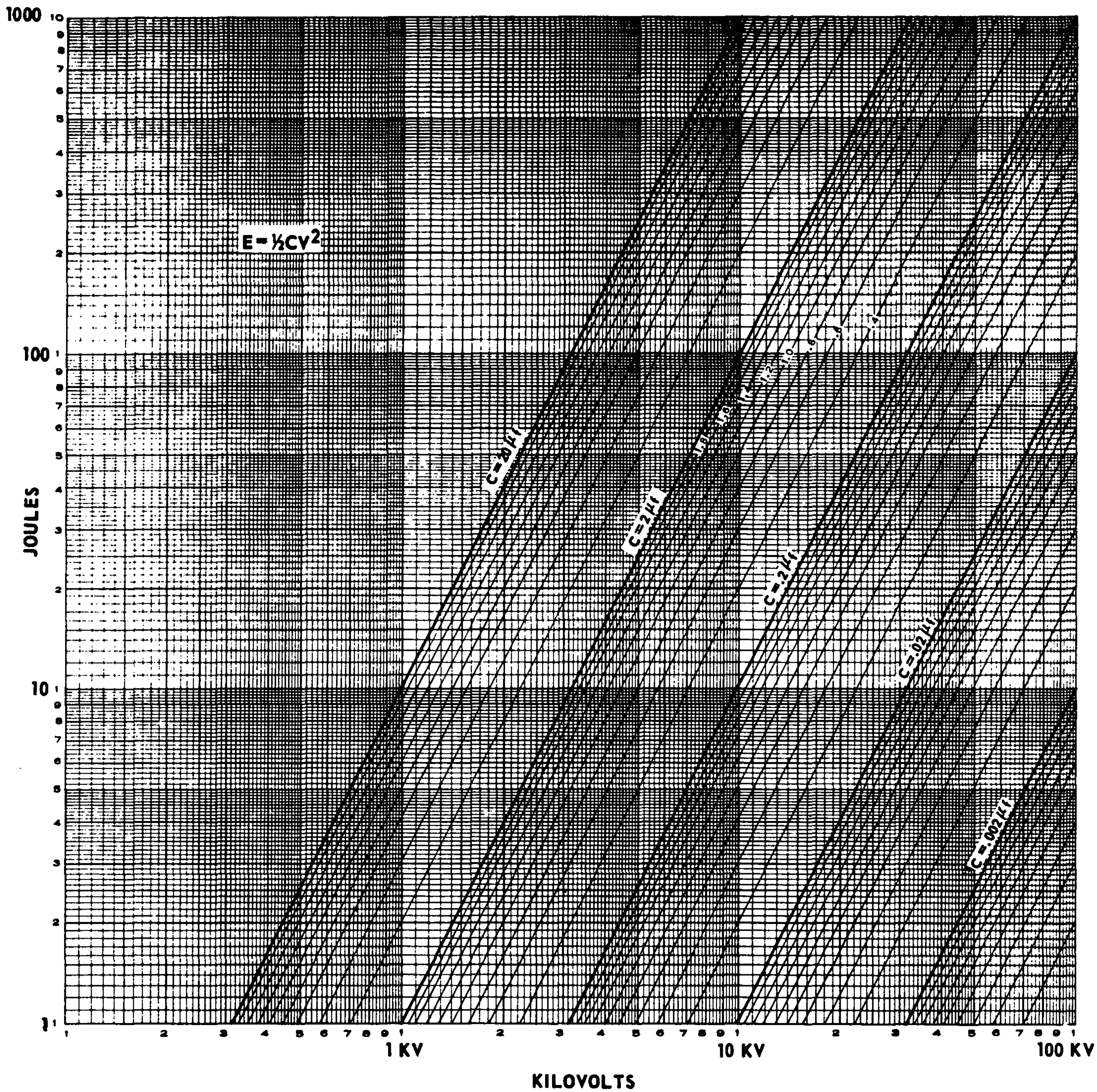


Figure 3-A-3. Plot of $E = 1/2\ CV^2$

ATTACHMENT B
ELECTROSTATIC SPARK IGNITION SUSCEPTIBILITY TEST PROCEDURE

3.B.1 PURPOSE

The purpose of the electrostatic spark ignition susceptibility tests is to determine the electrostatic sensitivity of various components of the XM15 and the E8 pyrotechnic fuse trains.

3.B.2 DESCRIPTION

Various materials and assemblies of materials will be subjected to electrostatic discharges of various energy levels to determine their sensitivity to electrostatic energy. Capacitance values and voltage levels will be varied to attain these various energy levels; capacitance discharge will be the mechanism by which the samples will be tested.

3.B.3 SCOPE

This procedure will be used for the investigation of the following items (in a subsystem configuration):

- Delay fuse line (XM15)
- Lead azide line (XM15)
- Small junction blocks (aluminum and lexan) (XM15)
- Large junction blocks (aluminum and lexan) (XM15)
- Ignition pellets (small and large) (XM15)
- Main fuse train (E8)
- Electrical squib (E8)
- Auxiliary fuse train (E8)
- E23 fuse train (E8)

3.B.4 REFERENCES

The following sources were utilized in preparing this procedure:

- U.S. Army Draft Technical Manual 3-1325-234-12
- U.S. Army Draft Technical Manual 3-1325-231-12
- "Pyrotechnic Materials: Their Resistivity, Charge Generation, and Sensitivity to Spark Discharge" by Arthur D. Little, Jr.
- Assembly Procedure for Canister Cluster Assembly, Chemical Agent, XM165

- Assembly Drawings E8 and XM15
- U.S. Army Technical Bulletin 3-1310-255-10

3.B.5 DEFINITIONS AND ABBREVIATIONS

None

3.B.6 RESPONSIBILITIES

3.B.6.1 TEST CONDUCTOR

The test conductor will be responsible for the performance of the test per procedure.

3.B.6.2 SAFETY

The safety representative will monitor the operation, render safety advice, and assure that the test is conducted in a safe manner.

3.B.7 SUPPORT REQUIREMENTS

3.B.7.1 SPECIAL TOOLS/TEST EQUIPMENT

The following tools/test equipment will be utilized for testing for electrostatic ignition susceptibility:

- Technician's tool box
- Fluke, Model 410B, high voltage P/S
- HV probe
- Spark gap test fixture
- Rule, calipers, or other instrument for measuring gaps

3.B.7.2 EQUIPMENT/MATERIALS

The equipment/materials required for this testing activity are:

- Assorted capacitors, 0.002-1.0 mfd, with voltage ratings to 10 kv
- Aluminum buss with 8-32 mounting holes
- Assorted test leads
- Freon cleaning agent

3.B.8 PREREQUISITES

A CO_2 fire extinguisher must be available during testing, and all personnel engaged in the testing activity must wear safety glasses or face shields.

3.B.9 TEST PROCEDURE

3.B.9.1 PREPARATION

Preparations for testing will be as follows:

a. Assemble the test equipment into the configuration shown in Figure 3-B-1.

b. Secure the specimen or components to be tested.

c. Ensure that all personnel within ten feet of the pyrotechnic test specimens are wearing safety glasses.

3.B.9.2 TEST

Actual testing will proceed as follows:

a. Verify that the high voltage power supply is off.

b. Place the test specimen in the test fixture (see Figure 3-B-1).

c. Ground the specimen as directed by the test conductor. Record the test configuration on the data sheet (Figure 3-B-2).

d. Turn on the high voltage power supply.

CAUTION

HIGH VOLTAGE. During the remaining steps high voltages will be present. Use extreme caution to prevent accidental contact with points of high voltage.

e. With all output voltage switches to zero, turn the high voltage power switch on.

f. In the approximately five seconds between steps, advance the output voltage switches to the test voltage specified by the test conductor. Record the final voltage on the data sheet.

g. Using the control knob, lower the spark gap test aid probe to the sample until a spark occurs.

h. Return the spark gap test aid probe to its original position.

i. Return the power supply high voltage output switches to zero.

j. Record observations and comments concerning the results of the test on the data sheet.

k. Clean the test surface and place the next specimen on the test fixture.

l. Repeat step 3.B.9.2.c.

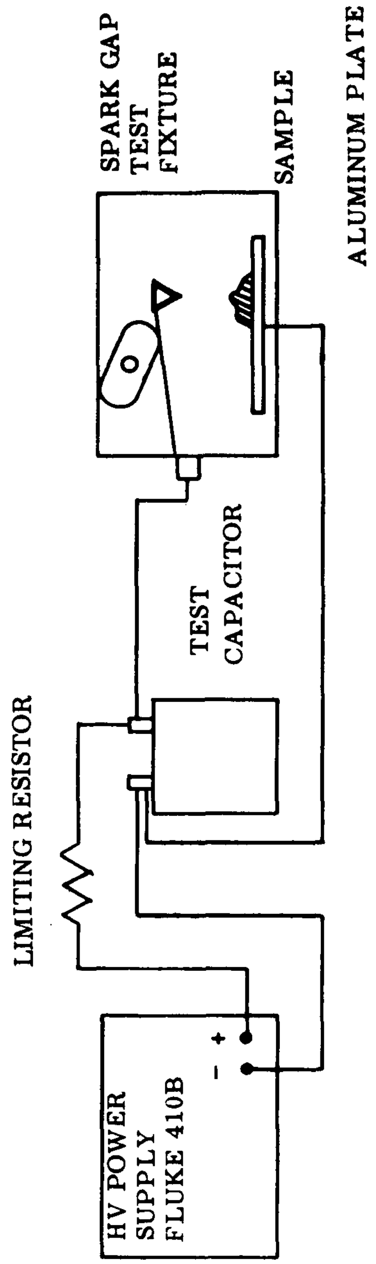


Figure 3-B-1. Electrostatic Ignition Susceptibility Test Setup

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE	HUMIDITY	DATE
					OBSERVATIONS AND COMMENTS		

Figure 3-B-2. Electrostatic Ignition Susceptibility Test Data Sheet

m. Repeat steps 3.B.9.2.e and k.

n. Upon completion of the test series, turn off the high voltage power supply.

o. Make the necessary calculations and complete the data sheet.

ATTACHMENT C
PRELIMINARY TESTS OF XM15 FUSE TRAIN

3.C.1 FIELD TEST

Prior to conducting lab electrostatic ignition tests on the elements of the XM15 fuse train, it is necessary to ignite the pellet, the fuse delay line, and the lead azide line in a field setup to determine if these elements can be safely ignited in a lab setup. The results of the following tests indicate that, with the necessary precautions, lab testing can be performed without creating undue hazards.

The following five ignition tests were conducted at the MTF Keller Road test range:

- Test 1 - Pellet in Small Junction Block (Lexan)
- Test 2 - Lead Azide and Pellet in Small Junction Block (Al)
- Test 3 - Lead Azide (In) Two Delay Lines (Out) and Pellet in Small Junction Block
- Test 4 - Delay Line Only
- Test 5 - Lead Azide and Small Junction Block

3.C.1.1 TEST 1 - PELLET IN SMALL JUNCTION BLOCK (LEXAN)

To provide for a clean ignition test, a fuse was inserted into the block and ignited by a small amount of black powder which was ignited by passing current through an imbedded wire. The black powder and wire technique was used as an ignition system for all of the remaining tests.

The pellet ignition was very similar to that of a large match; i.e., a small quick burning flash.

LAB PRECAUTION

Wear dark safety glasses.

3.C.1.2 TEST 2 - LEAD AZIDE AND PELLET IN SMALL JUNCTION BLOCK (Al)

When the lead azide line was ignited with black powder, a flame of less than one foot in height was observed along the line as it burned. The pellet reacted the same as during Test 1. A small "cap pistol type" noise occurred as the pellet ignited.

LAB PRECAUTION

Flame Hazard

3.C.1.3 TEST 3 - LEAD AZIDE (IN),TWO DELAY LINES (OUT) AND PELLET IN SMALL JUNCTION BLOCK

The lead azide line was ignited with black powder and produced the same results as did Tests 1 and 2. The burning of the delay line could not be seen because the lead sheath of the delay had melted in various places.

LAB PRECAUTION

Small dispersion of fine lead particles

3.C.1.4 TEST 4 - DELAY LINE ONLY

The delay line was ignited by black powder, and the delay line burning could not be seen (observed from approximately 25 feet). Results of this test were the same as those of Test 3.

3.C.1.5 TEST 5 - LEAD AZIDE AND SMALL JUNCTION BLOCK

Tests 2 and 3 produced a "cap pistol" noise when the pellet ignited. This test was conducted to determine whether the noise resulted from the lead azide burning in the confined area of the entrance hole in the block or from the ignition of the pellet. The same noise occurred as when the lead azide line burned into the junction block hole. This appears to account for the noise heard during the Dugway incident.

It may be of interest to conduct an ignition test with the lead azide line imbedded in the RTV to determine whether the cap pistol noise occurs in that configuration.

3.C.2 ELECTROSTATIC RESEARCH LABORATORY TESTS

The purpose of the following tests was mainly to familiarize personnel with materials and test methods, not to obtain data:

a. Material was ignited at a number of voltage and capacitance combinations, with the lowest 250 volts, 0.002 microfarads, for an energy of 0.00006 joules. Pellet material was found to ignite at any energy level down to 0.00006 joules, and probably lower. These ignitions occurred with the pellet material in a somewhat crumbled form. Apparently the pellet material will ignite at any energy level provided an arc can be produced and the pellet material is in the proper form (crumbled or powdered).

b. A short length of delay line (approximately 1/16 inch) was split down one side and laid open, exposing fuse material. The sample was ignited on the first attempt, with 500 volts, 0.002 microfarads, 0.00025 joules.

c. A short length of delay line (approximately 1/16 inch) with the lead and fuse material flush on both ends was ignited after several attempts, at 500 volts, 0.002 microfarad, 0.00025 joules. The several (4 or 5) attempts were all made under the same conditions.

d. A longer length of delay line (approximately 1 1/2 inch) with flush ends was ignited after several attempts, with 500 volts, 0.002 microfarads or .00025 joules.

e. A 1/4-inch pellet was ignited with 2500 volts, .01 microfarads, or 0.036 joules. Ignition did not occur with 2000 volts, .01 microfarads, or .02 joules.

ATTACHMENT D

ELECTROSTATIC SENSITIVITY OF THE XM15 FUSE TRAIN MATERIALS AND COMPONENTS

The data sheets included in the remainder of this attachment present the raw data of the spark ignition sensitivity tests of materials and components of the XM15 fuse train. (Also reference paragraph 3.4.2.)

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^{o} / HUMIDITY 57% / DATE 6/30/70 — OBSERVATIONS AND COMMENTS
1	Lead Azide Sample Arc to Center-Outer Sheath	.002	1,581	.0025	Arc to Sample (Very Small) No Visible Changes
2	Lead Azide Sample Arc to Center-Outer Sheath	.002	2,000	.004	Arc to Sample (Very Small) No Visible Changes
3	Lead Azide Sample Arc to Center-Outer Sheath	.002	3,000	.009	Arc to Sample (Very Small) No Visible Changes
4	Lead Azide Sample Arc to Center-Outer Sheath	.002	4,000	.016	Arc to Sample (Very Small) No Visible Changes
5	Lead Azide Sample Arc to Center-Outer Sheath	.002	5,000	.025	Arc to Sample (Very Small) No Visible Changes
6	Lead Azide Sample Arc to Center-Outer Sheath	.002	6,000	.036	Arc to Sample (Very Small) No Visible Changes
7	Lead Azide Sample Arc to Center-Outer Sheath	.1	2,000	.2	Arc to Sample (Very Small) No Visible Changes
8	Lead Azide Sample Arc to Center-Outer Sheath	.1	3,000	.45	Arc to Sample (Large) No Visible Changes
9	Lead Azide Sample Arc to Center-Outer Sheath	.1	4,000	.8	Arc to Sample (Large) No Visible Changes
10	Lead Azide Sample Arc to Center-Outer Sheath	.1	5,000	1.25	Arc to Sample (Large) No Visible Changes
11	Lead Azide Sample Arc to Center-Outer Sheath	.1	7,000	2.45	Arc to Sample (Large) No Visible Changes
12	Lead Azide Sample Arc to Center-Outer Sheath	.1	10,000	5.0	Arc to Sample (Very Large) No Visible Changes
13	Lead Azide Sample Arc to Center-Outer Sheath	1.0	10,000	50.0	Arc to Sample (Very Large) No Visible Changes

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 70° / HUMIDITY 64% / DATE 6/30/70 OBSERVATIONS AND COMMENTS
14	Lead Azide Arc Across End	.002	2,000	.004	Arc to Sample (Very Small) No Visible Changes
15	Lead Azide Arc Across End	.002	4,000	.016	Arc to Sample (Very Small) No Visible Changes
16	Lead Azide Arc Across End	.002	10,000	.1	Arc to Sample (Large) No Visible Changes
17	Lead Azide Arc Across End	0.1	5,000	1.25	Arc to Sample (Large) No Visible Changes
18	Lead Azide Arc Across End	0.1	10,000	5.0	Arc to Sample (Very Large) No Visible Changes
19	Lead Azide Arc Across End	1.0	10,000	50.0	Arc to Sample (Very Large) No Visible Changes
20	Lead Azide Thru End-Cross Section	0.1	2,000	.2	Arc to Sample (Very Small) No Visible Changes
21	Lead Azide Thru End-Cross Section	0.1	5,000	1.25	Arc to Sample (Large) No Visible Changes
22	Lead Azide Thru End-Cross Section	0.1	10,000	5.0	Arc to Sample (Very Large) No Visible Changes
23	Lead Azide Thru End-Cross Section	1.0	8,000	32.0	Arc to Sample (Very Large) No Visible Changes
24	Lead Azide-Half of Outer Sheath Cut Back- Arc thru Lead Azide	.002	1,000	.1	Arc to Sample (Very Small) No Visible Changes
25	Lead Azide-Half of Outer Sheath Cut Back- Arc Thru Lead Azide	.002	2,000	.004	Arc to Sample (Very Small) No Visible Changes
26	Lead Azide-Half of Outer Sheath Cut Back- Arc Thru Lead Azide	.002	4,000	.016	Arc to Sample (Small) No Visible Changes

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 70^o / HUMIDITY 64% / DATE 6/30/70 — OBSERVATIONS AND COMMENTS
27	Lead Azide-Half of Outer Sheath Cut Back-Arc Thru Lead Azide	.002	8,000	.064	Arc to Sample (Small) No Visible Changes
28	Lead Azide-Half of Outer Sheath Cut Back-Arc Thru Lead Azide	0.1	5,000	1.25	Arc to Sample (Large) No Visible Changes
29	Lead Azide-Half of Outer Sheath Cut Back-Arc Thru Lead Azide	1.0	6,000	1.8	Arc to Sample (Very Large) No Visible Changes
30	Delay Fuse Arc to Sheath	.002	1,000	.001	Arc
31	Delay Fuse Arc to Sheath	.002	5,000	.025	Arc
32	Delay Fuse Arc to Sheath	1.0	5,000	12.5	Ignited
33	Ignition Pellet	.002	1,000	.001	Arc, No Ignition
34	Ignition Pellet	.002	2,000	.004	Arc, No Ignition
35	Ignition Pellet	.002	5,000	.025	Ignition
36	Ignition Pellet	.002	2,500	.00625	Arc, No Ignition
37	Ignition Pellet	.002	3,000	.009	Arc, No Ignition
38	Ignition Pellet	.002	3,500	.01225	Arc, No Ignition
39	Ignition Pellet	.002	4,000	.016	Ignition

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 70^{o} / HUMIDITY 64% / DATE 6/30/70 — OBSERVATIONS AND COMMENTS
40	Ignition Pellet	.002	3,600	.01296	Arc, No Ignition
41	Ignition Pellet	.002	3,600	.01296	Arc, No Ignition
42	Ignition Pellet	.002	3,700	.01369	Arc, No Ignition
43	Ignition Pellet	.002	3,800	.01444	Arc, No Ignition
44	Ignition Pellet	.002	3,900	.01521	Arc, No Ignition
45	Ignition Pellet	.002	4,000	.016	Arc, No Ignition
46	Ignition Pellet	.002	4,100	.01681	Arc, No Ignition
47	Ignition Pellet	.002	4,200	.01764	Arc, No Ignition
48	Ignition Pellet	.002	4,300	.01849	Arc, No Ignition
49	Ignition Pellet	.002	4,400	.01936	Arc, No Ignition
50	Ignition Pellet	.002	4,500	.02025	Arc, No Ignition
51	Ignition Pellet	.002	4,600	.02116	Arc, No Ignition
52	Ignition Pellet	.002	4,700	.02209	Arc, No Ignition

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 70^0 / HUMIDITY 64% / DATE 6/30/70 — OBSERVATIONS AND COMMENTS
53	Ignition Pellet	.002	4,800	.02304	Arc, No Ignition
54	Ignition Pellet	.002	4,900	.02401	Arc, No Ignition
55	Ignition Pellet	.002	5,000	.025	Arc, No Ignition
56	Ignition Pellet	.002	6,000	.036	Arc, No Ignition
57	Ignition Pellet	.002	7,000	.049	Arc, No Ignition
58	Ignition Pellet	.002	5,000	.025	Changes Pellet Position Arc No Ignition

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 71^o / HUMIDITY 60% / DATE 6/30/70 — OBSERVATIONS AND COMMENTS
59	Ignition Pellet	.002	6,000	.036	Changed Pellet Position Arc No Ignition
60	Ignition Pellet	.002	7,000	.049	Changed Pellet Position Arc No Ignition
61	Ignition Pellet	.002	9,000	.081	Changed Pellet Position Arc No Ignition
62	Ignition Pellet	.002	5,000	.025	Changed Pellet Position Arc No Ignition
63	Ignition Pellet	.002	7,000	.049	Removed Pellet Arc No Ignition
64	Ignition Pellet	.002	4,000	.016	New Pellet Arc No Ignition
65	Ignition Pellet	.002	5,000	.025	Ignition
66	Ignition Pellet	.002	3,600	.01296	Ignition
67	Ignition Pellet	.002	3,000	.009	(Ignited) Old Unfired Pellet On End - Tests No. 58 thru 62

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^o — HUMIDITY 60% — DATE 7/1/70 — OBSERVATIONS AND COMMENTS
68	Delay Fuse Arc to Sheath	.1	1,000	.05	1-inch Length Fuse Arc
69	Delay Fuse Arc to Sheath	.1	2,000	.2	1-inch Length Fuse Arc
70	Delay Fuse Arc to Sheath	.1	3,000	.45	1-inch Length Fuse Arc
71	Delay Fuse Arc to Sheath	.1	4,000	.8	1-inch Length Fuse Arc
72	Delay Fuse Arc to Sheath	.1	5,000	1.25	1-inch Length Fuse Arc
73	Delay Fuse Arc to Sheath	.1	6,000	1.8	1-inch Length Fuse Arc
74	Delay Fuse Arc to Sheath	.1	7,000	2.45	1-inch Length Fuse Arc
75	Delay Fuse Arc To Sheath	.1	8,000	3.2	1-inch Length Fuse Arc
76	Delay Fuse Arc to Sheath	.1	9,000	4.05	1-inch Length Fuse Arc
77	Delay Fuse Arc to Sheath	.1	9,700	4.70	1-inch Length Fuse Arc
78	Delay Fuse Arc to Sheath	1.0	1,000	.5	1-inch Length Fuse Arc
79	Delay Fuse Arc to Sheath	1.0	2,000	2.0	1-inch Length Fuse Arc
80	Delay Fuse Arc to Sheath	1.0	3,000	4.5	1-inch Length Fuse Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72° HUMIDITY 60% DATE 7/1/70 — OBSERVATIONS AND COMMENTS
81	Delay Fuse	1.0	4,000	8.0	1-inch Length Fuse Arc
82	Delay Fuse	1.0	5,000	12.5	1-inch Length Fuse Arc
83	Delay Fuse	1.0	6,000	18.0	1-inch Length Fuse Arc
84	Delay Fuse	1.0	7,000	24.5	1-inch Length Fuse Arc
85	Delay Fuse	1.0	8,000	32.0	1-inch Length Fuse Arc
86	Delay Fuse	1.0	9,000	40.5	1-inch Length Fuse Arc
87	Delay Fuse	1.0	10,000	50.0	1-inch Length Fuse Arc
88	Delay Fuse	1.0	10,000	50.0	Rotated Fuse so That Thin Wall was Toward Discharge Point (Ignition)
89	Delay Fuse	1.0	5,000	12.5	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point
90	Delay Fuse	1.0	6,000	18.0	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point
91	Delay Fuse	1.0	7,000	24.5	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point
92	Delay Fuse	1.0	8,000	32.0	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point
93	Delay Fuse	1.0	9,000	40.5	Ignition

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^{0} / HUMIDITY 60% / DATE 7/1/70 — OBSERVATIONS AND COMMENTS
94	Delay Fuse	1.0	5,000	12.5	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
95	Delay Fuse	1.0	4,000	8.0	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
96	Delay Fuse	1.0	5,000	12.5	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
97	Delay Fuse	1.0	6,000	18.0	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
98	Delay Fuse	1.0	7,000	24.5	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
99	Delay Fuse	1.0	8,000	32.0	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
100	Delay Fuse	1.0	9,000	40.5	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
101	Delay Fuse	1.0	10,000	50.0	New Fuse, 1-inch, Placed so That Thinnest Wall is Toward Discharge Point (Ignited)
102	Delay Fuse	1.0	5,000	12.5	Rotated Sample (Ignited)
103	Delay Fuse	1.0	4,000	8.0	New Fuse Arc
104	Delay Fuse	1.0	5,000	12.5	New Fuse Arc
105	Delay Fuse	1.0	6,000	18.0	New Fuse Arc
106	Delay Fuse	1.0	7,000	24.5	New Fuse Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^{o} HUMIDITY 60% DATE 7/1/70 — OBSERVATIONS AND COMMENTS
107	Delay Fuse	1.0	8,000	32.0	New Fuse
108	Delay Fuse	1.0	9,000	40.5	Ignition
109	Delay Fuse Arc to Center Core	.002	100	.00001	Arc
110	Delay Fuse Arc to Center Core	.002	500	.00025	Ignition
111	Delay Fuse Arc to Center Core	.002	200	.00004	Arc
112	Delay Fuse Arc to Center Core	.002	300	.00009	Arc
113	Delay Fuse Arc to Center Core	.002	400	.00016	Ignition
114	Delay Fuse Arc to Center Core	.002	200	.00004	Arc
115	Delay Fuse Arc to Center Core	.002	300	.00009	Arc
116	Delay Fuse Arc to Center Core	.002	350	.0001225	Arc
117	Delay Fuse Arc to Center Core	.002	380	.0001444	Arc
118	Delay Fuse Arc to Center Core	.002	400	.00016	Ignition
119	Delay Fuse Arc to Center Core	.002	350	.0001225	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^0 / HUMIDITY 60% / DATE 7/1/70 — OBSERVATIONS AND COMMENTS
120	Delay Fuse Arc to Center Core	.002	390	.0001521	Arc
121	Delay Fuse Arc to Center Core	.002	400	.00016	Arc
122	Delay Fuse Arc to Center Core	.002	450	.0002050	Ignition
123	Delay Fuse Arc to Center Core	.002	350	.0001225	Ignition
124	Delay Fuse Arc to Center Core	.002	350	.0001225	Arc
125	Delay Fuse Arc to Center Core	.002	380	.0001444	Arc
126	Delay Fuse Arc to Center Core	.002	400	.00016	Arc
127	Delay Fuse Arc to Center Core	.002	450	.0002025	Arc
128	Delay Fuse Arc to Center Core	.002	500	.00025	Ignition

ATTACHMENT E

ELECTROSTATIC SENSITIVITY OF THE PELLETS WITH ASSORTED COATINGS FROM THE XM15 FUSE TRAIN

The data sheets included in the remainder of the attachment present the raw data of the spark ignition sensitivity tests of treated pellets from the junction block of the XM15 fuse train. The pellets were coated with various materials as explained in paragraph 3.4.3.

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
1	Large Aluminum Junction Block, with Parafin Coated Pellet and				
	Live Fuses Bonded with Silver Lacquer	1.0	1000	0.5	Arc
2	Large Aluminum Junction Block, with Parafin Coated Pellet and				
	Live Fuses Bonded with Silver Lacquer	1.0	2000	2.0	Arc
3	Large Aluminum Junction Block, with Parafin Coated Pellet and				
	Live Fuses Bonded with Silver Lacquer	1.0	3000	4.5	Fuse Going to Empty Side of Junction Block Ignited
4	Large Aluminum Junction Block, with Parafin Coated Pellet and				
	Live Fuses Bonded with Silver Lacquer	1.0	4000	8.0	Arc
5	Large Aluminum Junction Block, with Parafin Coated Pellet and				
	Live Fuses Bonded with Silver Lacquer	1.0	5000	12.5	Arc
6	Large Aluminum Junction Block, with Parafin Coated Pellet and				
	Live Fuses Bonded with Silver Lacquer	1.0	6000	18.0	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
7	Large Aluminum Junction Block, with Parafin Coated Pellet and Live Fuses Bonded with Silver Lacquer	1.0	7000	24.5	Arc
8	Large Aluminum Junction Block, with Parafin Coated Pellet and Live Fuses Bonded with Silver Lacquer	1.0	8000	32.0	Arc
9	Large Aluminum Junction Block, with Parafin Coated Pellet and Live Fuses Bonded with Silver Lacquer	1.0	9000	40.5	Arc
10	Large Aluminum Junction Block, with Parafin Coated Pellet and Live Fuses Bonded with Silver Lacquer	1.0	10,000	50.0	Arc
11	Large Aluminum Junction Block, with Parafin Coated Pellet and Live Fuses Bonded with Silver Lacquer	1.0	5000	12.5	Deliberately Ignited End of Fuse by Placing Probe on Fuse End. Pellet Did Not Ignite
12	Aluminum Paint Coating on Pellet and Fuse Ends	1.0	1000	0.5	Arc
13	Large Aluminum Junction Block	1.0	2000	2.0	Arc
14	Large Aluminum Junction Block	1.0	3000	4.5	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
15	Large Aluminum Junction Block	1.0	4000	8.0	Arc
16	Large Aluminum Junction Block	1.0	5000	12.5	Arc
17	Large Aluminum Junction Block	1.0	6000	18.0	Arc
18	Large Aluminum Junction Block	1.0	7000	24.5	Arc
19	Large Aluminum Junction Block	1.0	8000	32.0	Arc
20	Large Aluminum Junction Block	1.0	9000	40.5	Arc
21	Large Aluminum Junction Block	1.0	10,000	50.0	Fuse Ignited, Pellet Did Not
22	Large Aluminum Junction Block	1.0	4000	8.0	Deliberately Ignited End Fuse after Moving Pellet to Its Side of Block, Pellet Did Not Ignite
23	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	1000	0.5	Arc
24	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	2000	2.0	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
25	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	3000	4.5	Arc
26	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	4000	8.0	Arc
27	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	5000	12.5	Arc
28	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	6000	18.0	Arc
29	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	7000	24.5	Arc
30	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	8000	32.0	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
31	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	9000	40.5	Arc
32	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	10,000	50.0	Arc
33	Nitro Cellulose Coating on Pellet and Fuse Ends, Large Aluminum Junction Block	1.0	10,000	50.0	Arc

ATTACHMENT F

ELECTROSTATIC SENSITIVITY OF THE XM15 FUSE TRAIN JUNCTIONS AND SUBASSEMBLIES

ATTACHMENT F
ELECTROSTATIC SENSITIVITY OF THE XM15 FUSE TRAIN JUNCTIONS AND SUBASSEMBLIES

3.F.1 GENERAL

The data sheets included in this attachment present the raw data of the spark ignition sensitivity tests of junctions and subassemblies of the XM15 fuse train. Reference paragraph 3.4.4.

3.F.2 COMPARISON OF ALUMINUM AND AND LEXAN JUNCTION BLOCKS

The data related to the comparison of aluminum and lexan junction blocks are contained on pages 3-F-2 through 3-F-8.

3.F.3 SENSITIVITY OF JUNCTIONS WITH CONDUCTIVE CEMENT

The data related to the sensitivity of junctions with conductive cement are contained on pages 3-F-9 through 3-F-13.

3.F.4 STUDIES OF JUNCTION EFFECT ON SUBASSEMBLY SENSITIVITY

The data related to the studies of junction effects on subassembly sensitivity are contained on pages 3-F-14 through 3-F-19.

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^0 — HUMIDITY 60% — DATE 7/1/70 OBSERVATIONS AND COMMENTS
1	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	500	.00025	Arc
2	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,000	.001	Arc
3	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,500	.0025	Arc
4	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,000	.004	Arc
5	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,500	.00625	Ignition
6	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	500	.00025	Arc
7	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,000	.001	Arc
8	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,500	.0025	Arc
9	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,000	.004	Arc
10	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,500	.00625	Arc
11	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	3,000	.009	Arc
12	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	3,500	.01225	Arc
13	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	3,900	.01521	Ignition

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^o / HUMIDITY 60% / DATE 7/1/70 — OBSERVATIONS AND COMMENTS
14	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	500	.00025	Arc
15	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,000	.001	Arc
16	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,500	.0025	Arc
17	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,000	.004	Arc
18	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,500	.00625	Arc
19	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	3,000	.009	Fuse Flush with Wall, Gap Between Fuse and Pellet (Ignition)
20	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	500	.00025	Arc
21	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,000	.001	Arc
22	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	1,500	.0025	Arc
23	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,000	.004	Arc
24	Subassembly: Junction Block (Lexan), Fuse & Pellet	.002	2,500	.00625	Ignition
25	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	500	.00025	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 72^o / OBSERVATIONS AND COMMENTS	HUMIDITY 60%	DATE 7/1/70
26	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	1,000	.001	Arc		
27	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	1,500	.00225	Arc		
28	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	2,000	.004	Arc		
29	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	3,000	.009	Arc		
30	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	5,000	.025	Arc		
31	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	7,000	.049	Arc		
32	Subassembly: Junction Block (Aluminum), Fuse & Pellet	.002	9,500	.09025	Arc		
33	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	1,000	.05	Arc		
34	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	2,000	.2	Arc		
35	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	3,000	.45	Arc		
36	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	4,000	.8	Arc		
37	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	5,000	1.25	Arc		
38	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	6,000	1.8	Arc		
39	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	7,000	2.45	Arc		

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 69^o / HUMIDITY 64% / DATE 7/2/70 — OBSERVATIONS AND COMMENTS
40	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	8,000	3.2	Arc
41	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	9,000	4.05	Arc
42	Subassembly: Junction Block (Aluminum), Fuse & Pellet	0.1	10,000	5.0	Arc
43	Subassembly: Junction Block(Aluminum), Fuse & Pellet	1.0	1,000	0.5	Arc
44	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	2,000	2.0	Arc
45	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	3,000	4.5	Arc
46	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	4,000	8.0	Arc
47	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	5,000	12.5	Arc
48	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	6,000	18.0	Arc
49	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	7,000	24.5	Arc
50	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	8,000	32.0	Ignition (Not Known Whether Ignition Resulted from Fuse Ignition or Pellet)
51	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	2,000	2.0	Dummy Fuse Line Installed with Eastman 910
52	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	3,000	4.5	Ignition (Possible Fuse Insulated from Block by Glue)
53	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	2,000	2.0	Dummy Fuse Line, No Glue End Swaged for Solid Contact with Block

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 69° / HUMIDITY 64% / DATE 7/2/70 — OBSERVATIONS AND COMMENTS
54	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	3,000	4.5	Arc
55	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	4,000	8.0	Arc
56	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	5,000	12.5	Arc
57	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	6,000	18.0	Arc
58	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	7,000	24.5	Ignition
59	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Dummy Fuse Line, No Glue, No Pellet, End Swaged
60	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing between Fuse and Junction Block
61	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing between Fuse and Junction Block
62	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing between Fuse and Junction Block
63	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing between Fuse and Junction Block
64	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing Between Fuse and Junction Block
65	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing Between Fuse and Junction Block
66	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing Between Fuse and Junction Block
67	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing Between Fuse and Junction Block

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 69° HUMIDITY 64% DATE 7/2/70 — OBSERVATIONS AND COMMENTS
68	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing Between Fuse and Junction Block
69	Subassembly: Junction Block (Aluminum), Fuse & Pellet	1.0	10,000	50.0	Observed Random Arcing Between Fuse and Junction Block
70	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	1.0	1,000	0.5	Large J-Block, One Pellet
71	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	1.0	2,000	2.0	Arc
72	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	1.0	3,000	4.5	Ignition
73	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	1,000	0.025	Arc
74	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	2,000	0.1	Arc
75	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	3,000	.225	Arc
76	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	4,000	.4	Arc
77	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	5,000	.625	Arc
78	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	6,000	.9	Arc
79	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	7,000	1.225	Arc
80	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	8,000	1.6	Ignition
81	Large Junction Block (Aluminum), Fuse & One Pellet Subassembly	.05	1,000	0.025	No Pellets, Live Fuse Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 70°	HUMIDITY 60%	DATE 7/2/70
					OBSERVATIONS AND COMMENTS		
82	Large Junction Block - Fuse & Pellet Subassembly	.05	3,000	0.225	No Pellets, Live Fuse Arc		
83	Large Junction Block - Fuse & Pellet Subassembly	.05	4,000	.40	No Pellets, Live Fuse Arc		
84	Large Junction Block - Fuse & Pellet Subassembly	.05	5,000	.6125	Arc		
85	Large Junction Block - Fuse & Pellet Subassembly	.05	6,000	.9	Arc		
86	Large Junction Block - Fuse & Pellet Subassembly	.05	7,000	1.225	Arc		
87	Large Junction Block - Fuse & Pellet Subassembly	.05	8,000	1.6	Arc		
88	Large Junction Block - Fuse & Pellet Subassembly	.05	9,000	2.025	Arc		
89	Large Junction Block - Fuse & Pellet Subassembly	.05	10,000	2.5	Arc		

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY 1/2CV^2 (JOULES)	TEMPERATURE	HUMIDITY	DATE
					OBSERVATIONS AND COMMENTS		
1	Silver Lacquer	1.0	1000	0.5	Arc		
2	Silver Lacquer	1.0	2000	2.0	Arc		
3	Silver Lacquer	1.0	3000	4.5	Arc		
4	Silver Lacquer	1.0	4000	8.0	Arc		
5	Silver Lacquer	1.0	5000	12.5	Arc		
6	Silver Lacquer	1.0	6000	18.0	Arc		
7	Silver Lacquer	1.0	7000	24.5	Arc		
8	Silver Lacquer	1.0	8000	32.0	Arc		
9	Silver Lacquer	1.0	9000	40.5	Ignition		
10	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	1000	0.5	Arc		
11	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	2000	2.0	Arc		
12	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	3000	4.5	Arc		
13	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	4000	8.0	Arc		

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY 1/2CV^2 (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
14	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	5000	12.5	Arc
15	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	6000	18.0	Arc
16	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	7000	24.5	Arc
17	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	8000	32.0	Arc
18	Same as Test 1 Silver Lacquer with Dummy Fuse Line	1.0	9000	40.5	Ignition
19	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	1000	0.5	Arc
20	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	2000	2.0	Arc
21	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	3000	3.0	Arc
22	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	4000	8.0	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
23	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	5000	12.5	Arc
24	Same as Test 1 Silver Lacquer Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	6000	18.0	Arc
25	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	7000	24.5	Arc
26	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	8000	32.0	Arc
27	Same as Test 1 Silver Lacquer, Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	9000	40.5	Arc
28	Same as Test 1 Silver Lacquer, Dummy Fuse Line,				
	Also Pellet Coated with Silver Lacquer	1.0	10,000	50.0	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
29	Same as Test 1 Silver Lacquer Dummy Fuse Line;				
	Also Pellet Coated with Silver Lacquer	1.0	10,000	50.0	Arc
30	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	1000	0.5	Arc
31	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	2000	2.0	Arc
32	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	3000	4.5	Arc
33	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	4000	8.0	Arc
34	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	5000	12.5	Arc
35	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	6000	18.0	Arc
36	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	7000	24.5	Arc
37	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	8000	32.0	Arc
38	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	9000	40.5	Arc
39	Same as Test 1 Silver Lacquer Covering Delay Fuse and Pellet	1.0	10,000	50.0	Arc
40	Same as 31-39 Except Arc to Fuse Core to See if System Ignites	1.0	2000		Ignited Only the Fuse Line where Arc Struck

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE	HUMIDITY	DATE
					OBSERVATIONS AND COMMENTS		
41	Same Except without Coating Delay Fuse	1.0	2000		Same as 40		

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE	HUMIDITY	DATE
					OBSERVATIONS AND COMMENTS		
1	Refer to Configuration No. 5 of this report	1.0	200	0.02	Arc		
2	Refer to Configuration No. 5 of this report	1.0	500	0.175	Arc		
3	Refer to Configuration No. 5 of this report	1.0	700	0.245	Arc		
4	Refer to Configuration No. 5 of this report	1.0	1000	0.5	Arc		
5	Refer to Configuration No. 5 of this report	1.0	1500	1.125	Arc		
6	Refer to Configuration No. 5 of this report	1.0	2000	2.0	Arc		
7	Refer to Configuration No. 5 of this report	1.0	2500	3.125	Ignited One Pellet and Delay Fuse Only.		
8	Refer to Configuration No. 6 of this report	1.0	500	0.125	Arc		
9	Refer to Configuration No. 6 of this report	1.0	1000	0.5	Arc		
10	Refer to Configuration No. 6 of this report	1.0	1500	1.125	Arc		
11	Refer to Configuration No. 6 of this report	1.0	2000	2.0	Arc		
12	Refer to Configuration No. 6 of this report	1.0	2500	3.125	Arc		
13	Refer to Configuration No. 6 of this report	1.0	3000	4.5	Arc		

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE	HUMIDITY	DATE
					OBSERVATIONS AND COMMENTS		
14	See Test No. 8 for Configuration	1.0	3500	6.125	Arc		
15	See Test No. 8 for Configuration	1.0	4000	8.0	Arc		
16	See Test No. 8 for Configuration	1.0	4500	10.125	Arc		
17	See Test No. 8 for Configuration	1.0	5000	12.5	Arc		
18	See Test No. 8 for Configuration	1.0	5500	15.125	Arc		
19	See Test No. 8 for Configuration	1.0	6000	18.0	Arc		
20	See Test No. 8 for Configuration	1.0	6500	21.125	Arc		
21	See Test No. 8 for Configuration	1.0	7000	24.5	Arc		
22	See Test No. 8 for Configuration	1.0	7500	28.825	Arc		
23	See Test No. 8 for Configuration	1.0	8000	32.0	Arc		
24	See Test No. 8 for Configuration	1.0	8500	36.125	Arc		
25	See Test No. 8 for Configuration	1.0	9000	40.5	Arc		
26	See Test No. 8 for Configuration	1.0	9500	45.125	Arc		

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
27	See Test No. 8 for Configuration	1.0	10,000	50.0	Arc
28	See Test No. 8 for Configuration	1.0	500	0.125	Changing arcing point to lead azide.
29	See Test No. 8 for Configuration	1.0	1000	0.5	Arc
30	See Test No. 8 for Configuration	1.0	1500	1.125	Arc
31	See Test No. 8 for Configuration	1.0	2000	2.0	Arc
32	See Test No. 8 for Configuration	1.0	2500	3.125	Arc
33	See Test No. 8 for Configuration	1.0	3000	4.5	Arc
34	See Test No. 8 for Configuration	1.0	3500	6.125	Arc
35	See Test No. 8 for Configuration	1.0	4000	8.0	Arc
36	See Test No. 8 for Configuration	1.0	4500	10.125	Arc
37	See Test No. 8 for Configuration	1.0	5000	12.5	Arc
38	See Test No. 8 for Configuration	1.0	5500	15.125	Arc
39	See Test No. 8 for Configuration	1.0	6000	18.0	Arc

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
40	See Test No. 8	1.0	6500	21.125	Arc
41	See Test No. 8	1.0	7000	24.5	Arc
42	See Test No. 8	1.0	7500	28.825	Arc
43	See Test No. 8	1.0	8000	32.0	Arc
44	See Test No. 8	1.0	8500	36.125	Arc
45	See Test No. 8	1.0	9000	40.5	Arc
46	See Test No. 8	1.0	9500	45.125	Arc
47	See Test No. 8	1.0	10,000	50.0	Arc
					NOTE: Igniting center core of fuse line, small junction block removed. The pellets in the large junction block did
					not ignite. The input delay fuse to large block did ignite.
48	Refer to Configuration No. 4 of this report	1.0	1000	0.5	Arc
49	Refer to Configuration No. 4 of this report	1.0	2000	2.0	Arc
50	Refer to Configuration No. 4 of this report	1.0	3000	4.5	Ignition

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE — OBSERVATIONS AND COMMENTS
51	Refer to Configuration No. 3 of this report	1.0	1000	0.5	Arc
52	Refer to Configuration No. 3 of this report	1.0	1500	1.125	Arc
53	Refer to Configuration No. 3 of this report	1.0	2000	2.0	Arc
54	Refer to Configuration No. 3 of this report	1.0	2500	3.125	Ignition
55	Refer to Configuration No. 2 of this report	1.0	1000	0.5	Ignition
56	Refer to Configuration No. 1 of this report	1.0	500	0.175	Arc
57	Refer to Configuration No. 1 of this report	1.0	600	0.18	Arc
58	Refer to Configuration No. 1 of this report	1.0	700	0.245	Arc
59	Refer to Configuration No. 1 of this report	1.0	800	0.32	Arc
60	Refer to Configuration No. 1 of this report	1.0	900	0.405	Arc
61	Refer to Configuration No. 1 of this report	1.0	1000	0.5	Arc
62	Refer to Configuration No. 1 of this report	1.0	1500	1.125	Arc
63	Refer to Configuration No. 1 of this report	1.0	2000	2.0	Arc

3

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE	HUMIDITY	DATE
					OBSERVATIONS AND COMMENTS		
64	Refer to Configuration No. 1 of this report	1.0	2500	3.125	Arc		
65	Refer to Configuration No. 1 of this report	1.0	3000	4.5	Arc		
66	Refer to Configuration No. 1 of this report	1.0	3500	6.125	Arc		
67	Refer to Configuration No. 1 of this report	1.0	4000	8.0	Arc		
68	Refer to Configuration No. 1 of this report	1.0	5000	12.5	Arc		
69	Refer to Configuration No. 1 of this report	1.0	6000	18.0	Arc		
70	Refer to Configuration No. 1 of this report	1.0	7000	24.5	Ignition (Fuse on ground side did not ignite).		

SECTION 4
TRIBOELECTRIFICATION SUSCEPTIBILITY

4.1 INTRODUCTION

Electrostatic discharge and hence spark ignition of an item is not possible if electric fields are nonexistent. The primary methods of production of charge separation and hence electric fields are by transfer of charge from an external previously charged object or by frictional contact between components. The latter process is referred to as triboelectrification.

All materials have a characteristic capability for charge transfer to dissimilar materials. The charge transferred under controlled conditions between two materials will always be in the same direction. By performing such tests on a series of materials, the materials can be ranked relative to the others as to its affinity as an electron acceptor or donor at the interface with other materials. (Several such series are reported in the Phase I report, paragraph 3.3.)

To establish the situations in which possible electrostatic spark ignition of an item is possible, a series of triboelectric tests were performed. Samples of the various materials were subjected to contact and friction with materials which would normally be adjacent to them during either manufacturing, shipping, or handling. The frequency and duration of the contact or friction were selected so as to simulate as closely as possible the actual triboelectric conditions encountered by the E8 and XM15.

By this method, a determination was made of which materials, under what conditions, were likely to produce charges of magnitudes sufficient to prematurely activate these items.

4.2 TECHNIQUE

Both contact (no rubbing) and frictional contact tests were performed. Surfaces were carefully controlled. A detailed outline of the triboelectrification susceptibility test procedure is presented in Attachment A to Section 4. The magnitude and sign of the charge transferred are proportional to the electrostatic voltage as measured with an electrometer, held near the material's recently rubbed surface.

4.3 RESULTS OF XM15/XM165 TESTS

All tests were repeated 10 times. The average of these 10 tests is reported in Table 4-1. The situation in which the various pairs of material come into contact is also indicated. Note that potentials in the range of 10 kv are readily obtainable on the plastic surfaces (surlyn, urethane, and polyethylene).

Table 4-1. XM15/XM165 Triboelectrification Susceptibility Test Results

Material Pairs	Contact Voltage*	Friction Voltage*	Contact Situation Simulated
Surlyn Horse Hair	.35 .05	12.0 .15	In contact during packing, shipping and unpacking
Surlyn Plywood	.30 .05	6.0 .10	In contact during packing, shipping and unpacking
Surlyn Fiberboard	.20 .05	9.0 .10	In contact during packing, shipping and unpacking
Surlyn Copper	.10 .03	2.5 .15	In contact during packing, shipping and unpacking
Surlyn Urethane	.20 .80	-6.0 10.0	In contact during packing, shipping and unpacking
Surlyn Polyethylene	.20 1.5	-3.0 6.0	In contact during packing, shipping and unpacking
Surlyn Polystyrene	.15 1.0	2.0 5.5	In contact during packing, shipping and unpacking
Surlyn Cotton Cloth	.40 0	-8.0 0	In contact during the filling operation of expulsion charge bags with black powder

* All values listed are the average of 10 similar tests for each step. The units are due in kv. Relative Humidity: 50%; Temperature: 78° F.

4.4 RESULTS OF E8 TESTS

Table 4-2 displays the average results of 10 identical triboelectric tests of pairs of E8 components and packaging materials. The Royalite case was observed to rapidly dissipate charge accumulations. The urethane foam is the only component material which attains potentials in the 10 kv range, a characteristic which it achieves readily.

Table 4-2. E8 Triboelectrification Susceptibility Test Results

Material Pairs	Contact Voltage*	Friction Voltage*	Contact Situation Simulated
Royalite Wood	.45 .02	4.0 .05	In contact during packing, shipping and unpacking
Royalite Teflon	.60 .80	1.0 3.0	In contact during packing, shipping and unpacking
Royalite Aluminum Plate	.05 .01	.27 .01	In contact during packing, shipping and unpacking
Urethane Foam Teflon	2.0 -1.0	9.0 -6.0	In contact during packing, shipping and unpacking
Urethane Foam Royalite	.80 .20	7.0 -2.0	In contact during packing, shipping and unpacking
Urethane Foam Wood	1.0 .05	10.0 .08	In contact during packing, shipping and unpacking
Urethane Foam Aluminum Plate	.08 .02	3.0 .03	In contact during packing, shipping and unpacking
Urethane Foam Aluminum Foil	1.0 .09	11.0 .15	In contact during packing, shipping and unpacking

* All values listed are the average of 10 similar tests for each step. The units due in kv
Relative Humidity: 50%; Temperature: 78°F.

ATTACHMENT A

TRIBOELECTRIFICATION SUSCEPTIBILITY TEST PROCEDURE

4.A.1 PURPOSE

The purpose of the triboelectrification susceptibility test is to determine the susceptibility of various components of the E8 and XM165/XM15 weapons to triboelectrification.

4.A.2 DESCRIPTION

Various materials will be placed in contact with each other and then separated, and the triboelectric potential will be measured. Frictional contact will also be made, and the resulting potentials will be measured.

4.A.3 SCOPE

This procedure will be used only for the investigation of the triboelectric effects of the E8 and XM15 pyrotechnic fuse train.

4.A.4 REFERENCES

The following sources were utilized in preparing this procedure:

- U.S. Army Draft Technical Manual 3-1325-234-12
- U.S. Army Draft Technical Manual 3-1325-231-12
- Assembly Drawings E8 and XM15

4.A.5 DEFINITIONS AND ABBREVIATIONS

None

4.A.6 RESPONSIBILITIES

4.A.6.1 TEST CONDUCTOR

The test conductor will be responsible for the performance of the test per procedure.

4.A.6.2 SAFETY

The safety representative will monitor the operation, render safety advice, and assure that the test is conducted in a safe manner.

4.A.7 SUPPORT REQUIREMENTS

4.A.7.1 SPECIAL TOOLS/TEST EQUIPMENT

The following tools/test equipment will be utilized for testing for triboelectrification susceptibility:

- Technician's tool box
- Keithley Model 610B or 610C electrometer and Model 2501 head
- Statitrol Corporation Model M-1001 static meter
- Customer Materials, Inc., Model CM 1-7777 static meter
- Temperature/humidity recorder

4.A.7.2 EQUIPMENT/MATERIALS

Equipment/materials required for this testing activity are:

- Glass sheet, 18 inches x 18 inches x .125 inch (6 pieces)
- Rubber gloves (2 sets)
- Freon cleaning agent

4.A.8 PREREQUISITES

Prior to initiation of the test activity, the test conductor will select the material pairs to be tested.

4.A.9 TEST PROCEDURE

4.A.9.1 PREPARATION

Preparations for testing will be as follows:

a. Clean the rubber gloves thoroughly with Freon after they have been placed on hands (do not rub Freon).

b. Clean the sheets of Plexiglas thoroughly with poured Freon.

c. Place the pieces of Plexiglas into two stacks of three each, using clean gloves or paper towels to prevent contamination.

d. Clean the samples with Freon when possible, being careful not to touch them with the hands.

NOTE

Some samples may react with Freon.

4.A.9.2 TEST

4.A.9.2.1 Contact Electrification

Contact electrification testing will be conducted as follows:

a. Wearing cleaned rubber gloves, grasp the two samples, bring them into gentle contact, then separate them. Record the samples on the data sheet (Figure 4-A-1).

b. Place each sample on a Plexiglas sheet.

c. Using the Keithley Model 610C electrometer, measure the electrostatic potential of each material. Record on the data sheet.

4.A.9.2.2 Friction Electrification

Friction electrification testing will be conducted as follows:

a. Wearing cleaned rubber gloves, grasp the two samples and rub the surfaces together (back and forth) for 10 strokes.

b. Place each sample on a Plexiglas sheet.

c. Using the Keithley Model 610B or 610C electrometer, measure the electrostatic potential of each material. Record on the data sheet.

d. Repeat steps of 4.A.9.2.1 and 2 for each pair of materials.

DATA SHEET

MATERIAL A / MATERIAL B	CONTACT VOLTAGE	FRICTION VOLTAGE	COMMENTS

Figure 4-A-1. Triboelectrification Susceptibility Test Data Sheet

SECTION 5
SPECIAL TESTS

5.1 INTRODUCTION

In the course of component testing, several modifications have been suggested on the XM15 fuse train. These local modifications were verified in a series of special tests reported in paragraphs 3.4.4, 3.4.2.4, and 3.4.5. The effectiveness of these modifications as implemented by the manufacturers on reducing the ignition sensitivity of the unit was an additional special test.

Special tests as requested by Edgewood Arsenal personnel were also performed. These tests included determination of the electric fields which result from the foaming operation during normal manufacture of the E8 units. This analysis was related to determining the cause of an inadvertent functioning during the foaming operation. These data were also used to determine the magnitude of the residual, imbedded charge in the foam which is available for later discharge.

5.2 XM15 FUSE TRAIN SUBSYSTEM SPARK IGNITION SENSITIVITY TEST

5.2.1 GENERAL

This test was very similar to the electrostatic ignition test defined in paragraph 3.2 and the same test procedure was used. However, instead of applying a spark, energy was applied directly to the fuse train as shown in Figure 5-1. This simulated an electrostatic voltage being applied to the fuse train. The spark gap test fixture as defined in paragraph 3.2 was used to discharge the fuse train potential. Various voltages and capacitors were used to yield energies up to 50 joules. This test method simulated, in a subsystem mode, realistic situations to which the fuse train is exposed. A total of three fuse trains were tested as delivered from the Thiokol Chemical Corporation. Three additional units from Brunswick Corporation (the second of the two XM15 maunfacturers) will be tested after receipt as part of the follow-on project. This procedure ensures that actual samples are tested and eliminates the possibility of inducing unrealistic manufacturing errors.

5.2.2 PROCEDURE

The XM15 units tested were manufactured and supplied by the Thiokol Chemical Corporation, Woodbine, Georgia. The objective was to establish the electrostatic spark ignition sensitivity of the unit by discharging a capacitor across the extremities of the fuse train. Both the capacitance and charging voltage were determined; therefore, the energy in the pulse is established ($E = 1/2\ CV^2$).

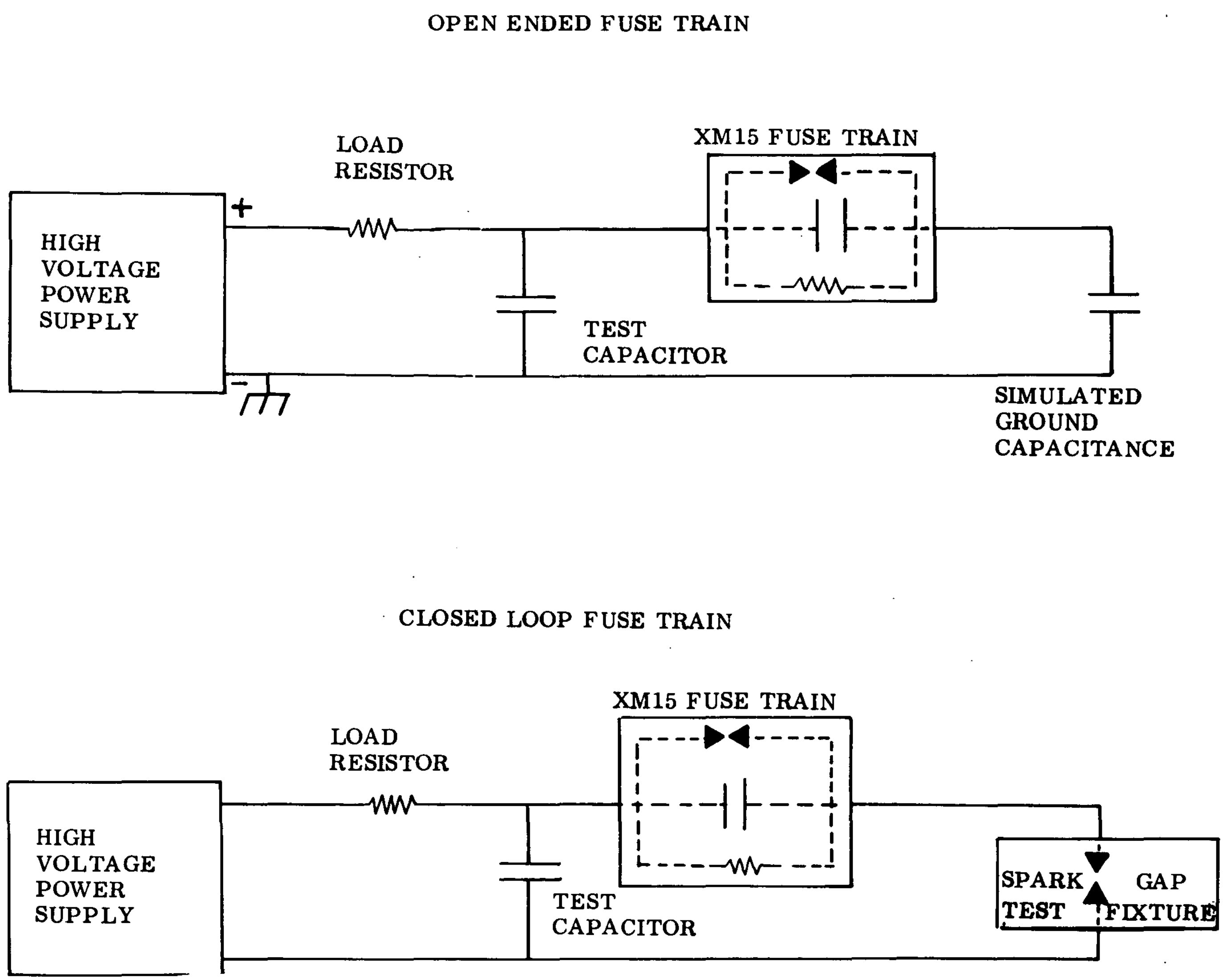


Figure 5-1. XM15 Fuse Train Subsystem Test Setup

The test equipment schematic diagram is shown in Figure 5-1. The fuse train was connected in series to the high voltage leads. The points of connection were at the large junction blocks located at each end of fuse train, subjecting the entire unit to the discharge pulse.

The test equipment and procedure are outlined in Attachment A to Section 5. Initially, low energies were discharged across the specimen with subsequent repetitions at increasing energy levels until ignition occurred. The fuse trains tested were modified to withstand discharges up to 40 joules; this corresponds to a discharge of a 1μf capacitor charged to 9 kv.

5.2.3 RESULTS

The first charging voltage was 100 v (an energy of 0.005 joules); and, as expected upon discharge of the capacitor, there was no ignition. The second charging voltage was 1 kv (an energy of 0.5 joules); and, contrary to expectations, when discharge occurred, ignition was induced. This pulse energy is approximately two orders of magnitude below the expected minimum ignition sensitivity.

The second unit was subjected to discharge from a 0.002 μf capacitor (high voltage pulse lead attached to one junction block but no return lead attached to system). No ignition occurred up to 9.9 kv charging voltage. The second test series was performed in a closed loop configuration (return lead provided). Ignition on sensitivity was bracketed to the [0.036 - 0.042] joule range, with ignition occurring at 6.5 kv.

The third sample was subjected to closed loop testing. Capacitors of 0.002 and 0.01 μf charged to the 8-9 kv level failed to ignite the unit. A 0.02 μf capacitor, discharged at 6.2 kv, ignited the unit. The ignition sensitivity was bracketed between [0.36 - 0.38] joules.

The data sheets from all three tests are included in Attachment B to this section.

5.2.4 OBSERVATIONS

Because of the low energy level of ignition, a piece-by-piece inspection of all components in the fuse train was conducted.

After removing the RTV compound from the fuse lines and junction blocks, several possible problem areas were detected on the extended fuse train, as follows:

- The metallic cement used for bonding the lead fuse lines to the aluminum junction blocks was not adhering to the lead line (see Figure 5-2). Resistance between these points on several lines ranged from 8 ohms to $>10^8$ ohms. Often, the reading was affected when the line was moved.
- The metallic cement appeared to cause a lacquer-colored scale to form between the circumference of the lead fuse line and its associated hole in the junction block. Resistance between the lead lines and junction blocks in this condition was from

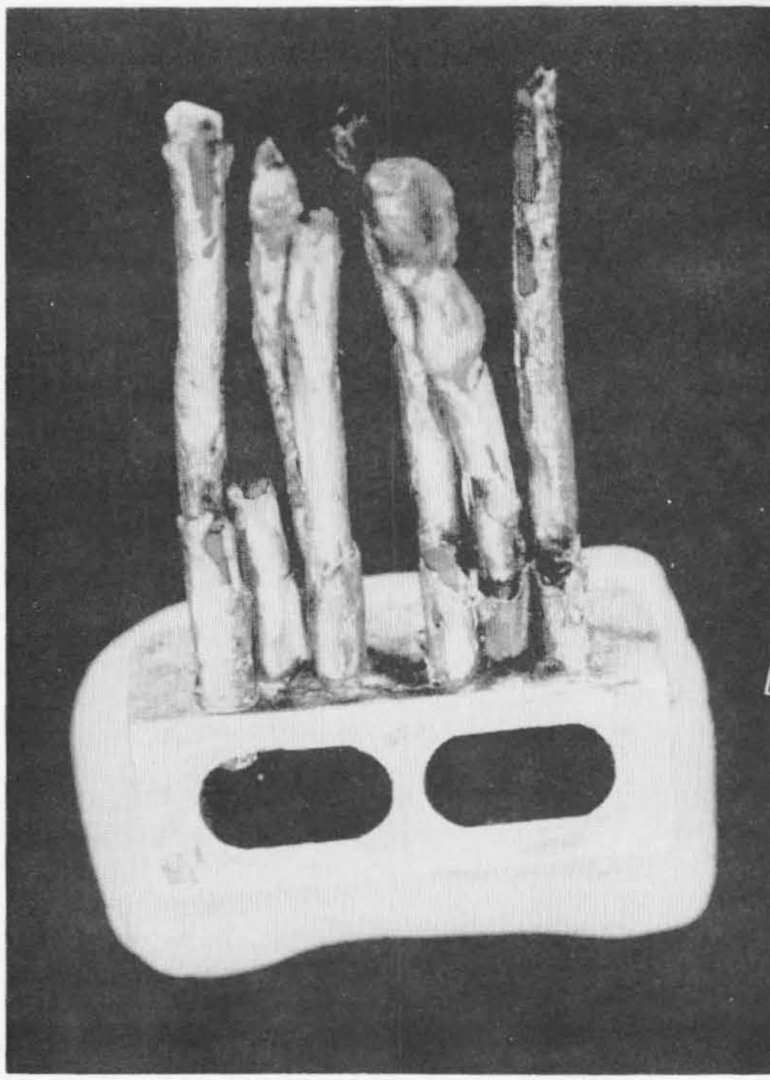


Figure 5-2. Expended Junction Block-Fuse Connection (Front View)

10^6 ohms to $>10^8$ ohms. The possibility that this condition occurred after ignition as a result of the heat of reaction is under investigation.

- Only one-third of the lead fuse lines were cemented to the junction blocks (see Figure 5-3). The remainder were either in loose contact or had a thin layer of RTV surrounding the end of the lead fuse line (see Figure 5-4), insulating it from its associated hole in the junction block. Resistance between the lead fuse lines and junction blocks in this condition was $>10^8$ ohms.

A theoretical description of the equivalent circuit and predictions appropriate to this test are presented in paragraph 2.3.

5.3 E8 FOAMING TEST

5.3.1 GENERAL

All voids in the E8 launcher module between the case and the launcher tubes are filled with polyurethane foam as shown in Figure 3-2. This filling is a two-step operation to permit an aluminum foil vapor barrier (Item 3 in Figure 3-2) to be imbedded in the foam.

The source of two fires in the E8 CS chemical agent canister backpack production facilities has been traced to the polyurethane plastic foaming operations. It was theorized that the foaming plastic generated static electricity as it expanded against the other nonconductive materials inside the E8 case. As a result of the tests conducted, it is now known that a static charge is generated during the top plate removal step of the foaming process.

The aluminum foil vapor barrier placed across the top of the foamed areas provides an excellent collection point for this static charge. If the electric field between the foil barrier and the fuse train exceeds the dielectric strength of the foam at the position of closest approach of the two components, then a discharge will occur. The capacitance of the system may be sufficiently high to supply a spark with sufficient energy to initiate the fuse train.

Figure 5-3. Expended Junction Block-Fuse Connection (Back View)

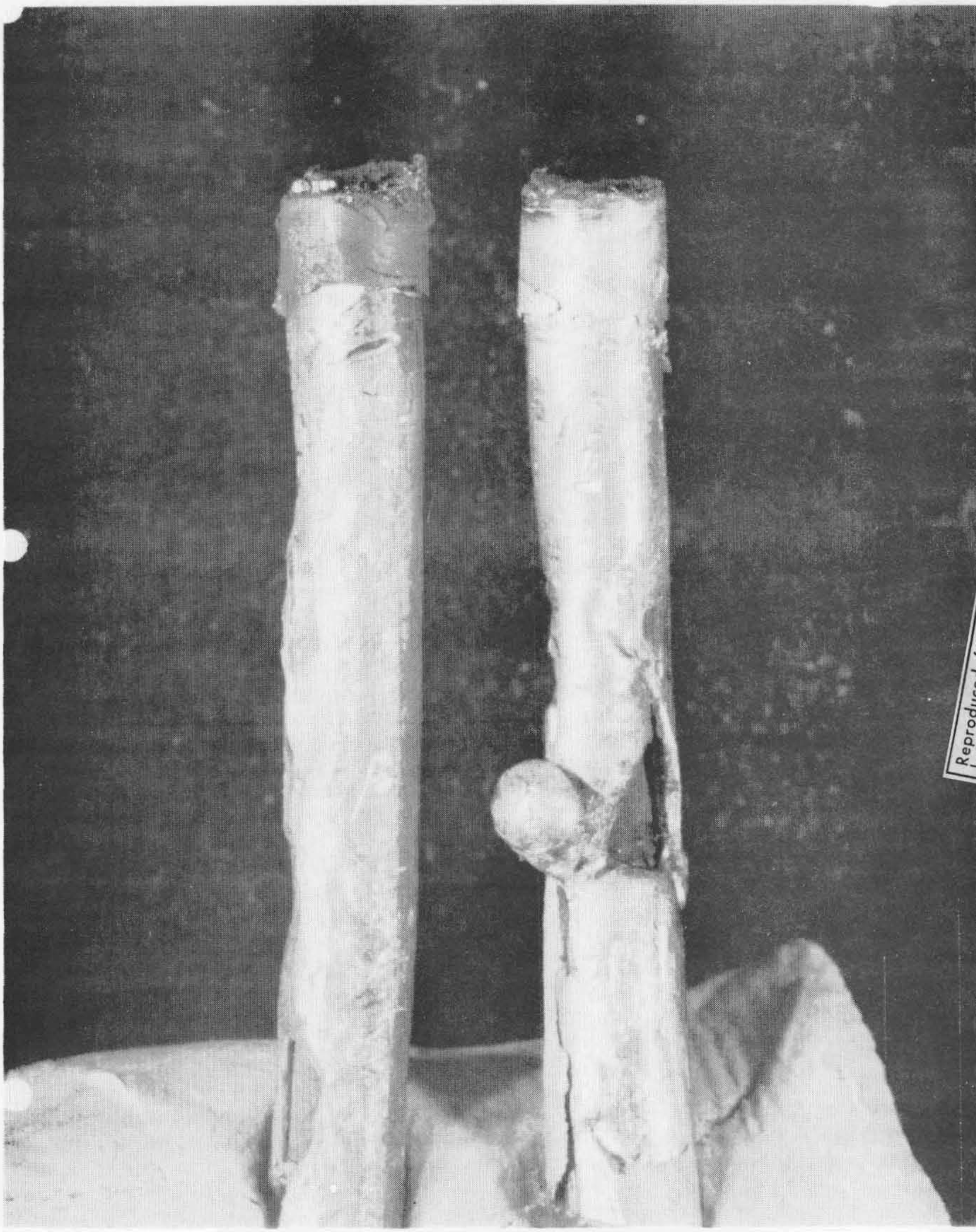


Figure 5-4. Expended Fuses Extracted from Junction Blocks (Left Fuse Coated with RTV, Right with Conductive Epoxy)

5.3.2 DESCRIPTION OF THE INCIDENT

According to statements made by Brunswick personnel, it is believed that the accident happened in the manner described in the following paragraphs.

During the foaming process, an E8 canister functioned prematurely, sending its E23 canisters in all directions within the immediate area of the foaming room.

The top plate (Figure 5-5) was being removed from the foamed vapor barrier when the incident occurred. This step is necessary since the aluminum foil vapor barrier is impressed on foam by the first foaming step. A second layer of foam is then poured over the foil, filling the void left by the vapor barrier top plate (Figure 5-6). Both top covers are secured into position by wing nuts (Figure 5-7). The uncured foam is sprayed into the canister in a liquid state and the top cover is secured into place. The foam then expands, filling the void. Approximately 20 minutes are required for curing. The cured foam adheres very strongly to the top cover, making removal difficult. The wing nuts are removed and the top cover is literally "knocked off."

It was during the cover removal process after the second foaming operation that the canister functioned. The E8 canister then dispersed all of its E23 canisters through their respective launch tubes, and all of the workers immediately cleared the area.

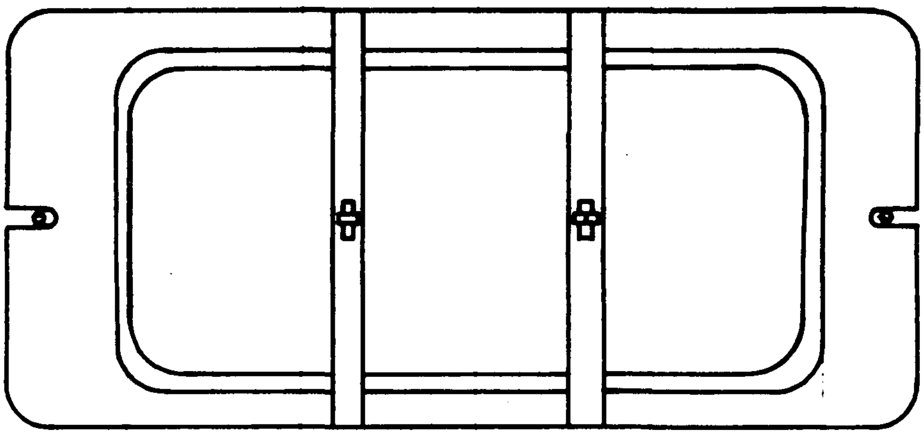
After the CS gas had dissipated, inspectors entered the foaming area and inspected the spent E8 module. It was observed that the insulation removed to perform a splice on fuse wires was not replaced, leaving the splice bare. In addition, the splice had not been tucked down into the bottom of the case as prescribed; rather, it was located above the external fuse hook-up housing (Figure 3-5) with its bare end positioned approximately 3/8-inch from the aluminum vapor barrier edge.

It is believed that when the top cover was knocked off, a high electrostatic potential was generated in the capacitor formed by the aluminum vapor barrier and the bare wire splice. The electric field exceeded the dielectric strength of the foam, resulting in a discharge sufficient to induce electrical ignition of the fuse train.

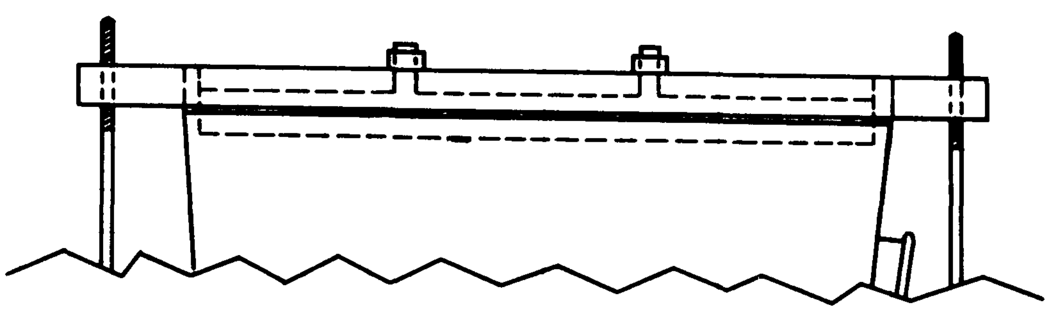
Based on this incident, the primary objective of this study was to determine the validity of the assumption that a potential is formed during top cover removal which is sufficient to exceed the dielectric strength of 3/8-inch of foam.

5.3.3 FACILITY CONDITIONS

The extent of charge buildup on a system is a function of its electrical isolation from ground. If the system is conductive and good conductivity is maintained to ground, electrostatic potentials will be minimized.

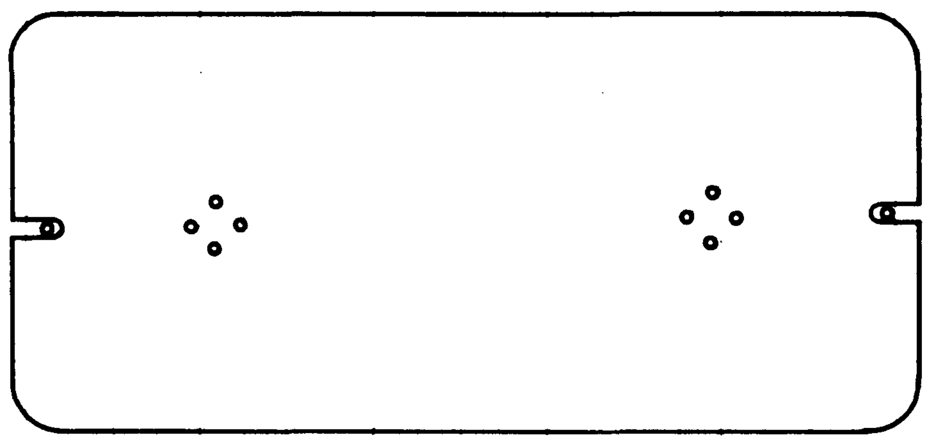


TOP VIEW

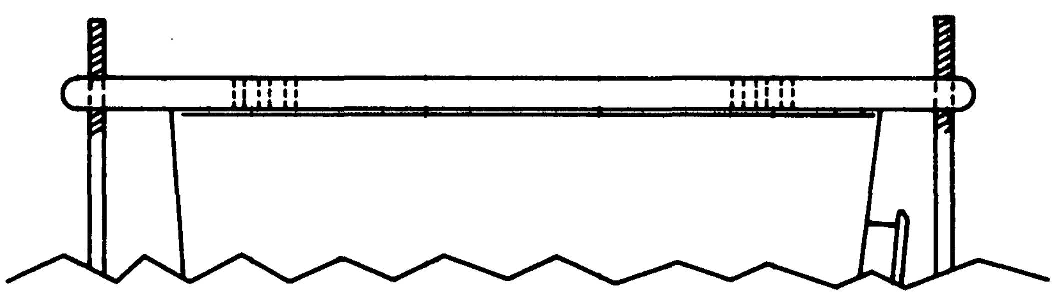


SIDE VIEW

Figure 5-5. Top Cover Plate Used for First Foaming



TOP VIEW



SIDE VIEW

Figure 5-6. Top Cover Plate Used for Second Foaming

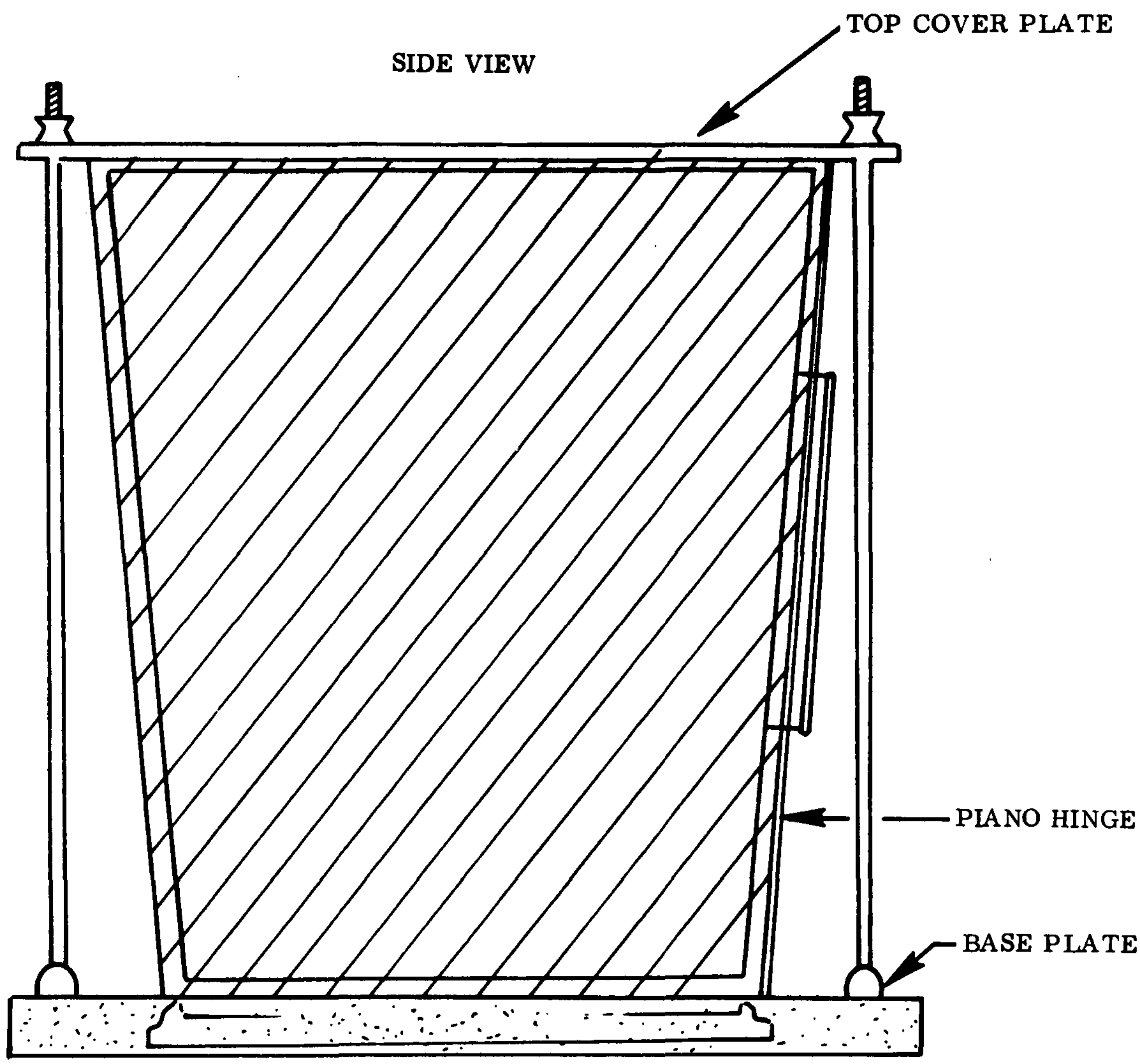


Figure 5-7. E8 Backpack Module Encased in Wood Frame Mold

The facility has a conductive floor connected to ground, and all personnel are required to wear conductive shoes and clothing to minimize electrostatic buildup. Prior to entering the facility, a conductivity meter is used to measure the conductivity through the shoes, verifying acceptable conductivity to ground. Personnel stand on two plates, one foot on each, and press a lever with one hand which connects them into the circuit, measuring the conductivity through each shoe and clothing. This ensures (provided their shoes remain in good contact with the floor) that all personnel are grounded at all times. All tables, chairs, benches, etc., are conductive and grounded.

Electrostatic charge is bled off exposed surfaces by atmospheric conductivity, which increases with increasing humidity. The doors stay open and the outside air is allowed to circulate freely throughout the building. There are no humidity controls in the main processing area. The external humidity on the day of the incident was between 40 and 50 percent.

5.3.4 ELECTROSTATIC MEASUREMENTS TAKEN DURING FOAMING OPERATION

The scope of the investigation was extended to determine the presence of electrostatic potentials throughout the foam process area and adjacent to the E8 backpack, since it is possible for a residual electrostatic charge to be built into the E8 backpack cluster. During the investigation, a Keithley Instruments, Inc., static meter, Model 610B, and associated 2501 static detecting head were used to measure local electrostatic potentials. This system measures the potential between an object and the head or the absolute potential of the electrostatic field at the head. All measurements were taken with the meter head 3/8-inch away from the object to be measured. Measurements were taken sequentially at the locations indicated in Figures 5-8 to 5-11.

This investigation was conducted several months after discontinuation of the E8 manufacturing. Under the direction of Brunswick personnel, a foaming operation setup was simulated to re-enact the original conditions as closely as possible. The room in which the test was conducted was approximately 78° F. Inside relative humidity was unknown, but doors opening to the outside conditions of 90 percent relative humidity and freezing temperatures were continuously in use.

Two E8 backpack modules were used for the test. Both modules were complete, except that the launch tubes were empty and capped. All fuse trains and fuse cloths were installed. The two modules were placed on a wooden pallet four inches above a concrete floor.

The electrostatic potential of module 1 was measured prior to foaming. The potential of both the case and the wooden pallet was measured and found to be zero. The module was then encased by a wood frame mold (Figure 5-5) to keep the sides of the module from expanding due to the pressure of the curing foam and to provide an upper lip for the vapor barrier. Foam was then injected into the module, filling all voids. Immediately after the foam was injected, the top lid, with aluminum foil vapor barrier attached (Figure 5-6), was clamped securely into place; and the foam was allowed to expand and cure. During this curing process, voltage measurements gave null readings. After the normal 20-minute curing period, voltage measurements again were zero.

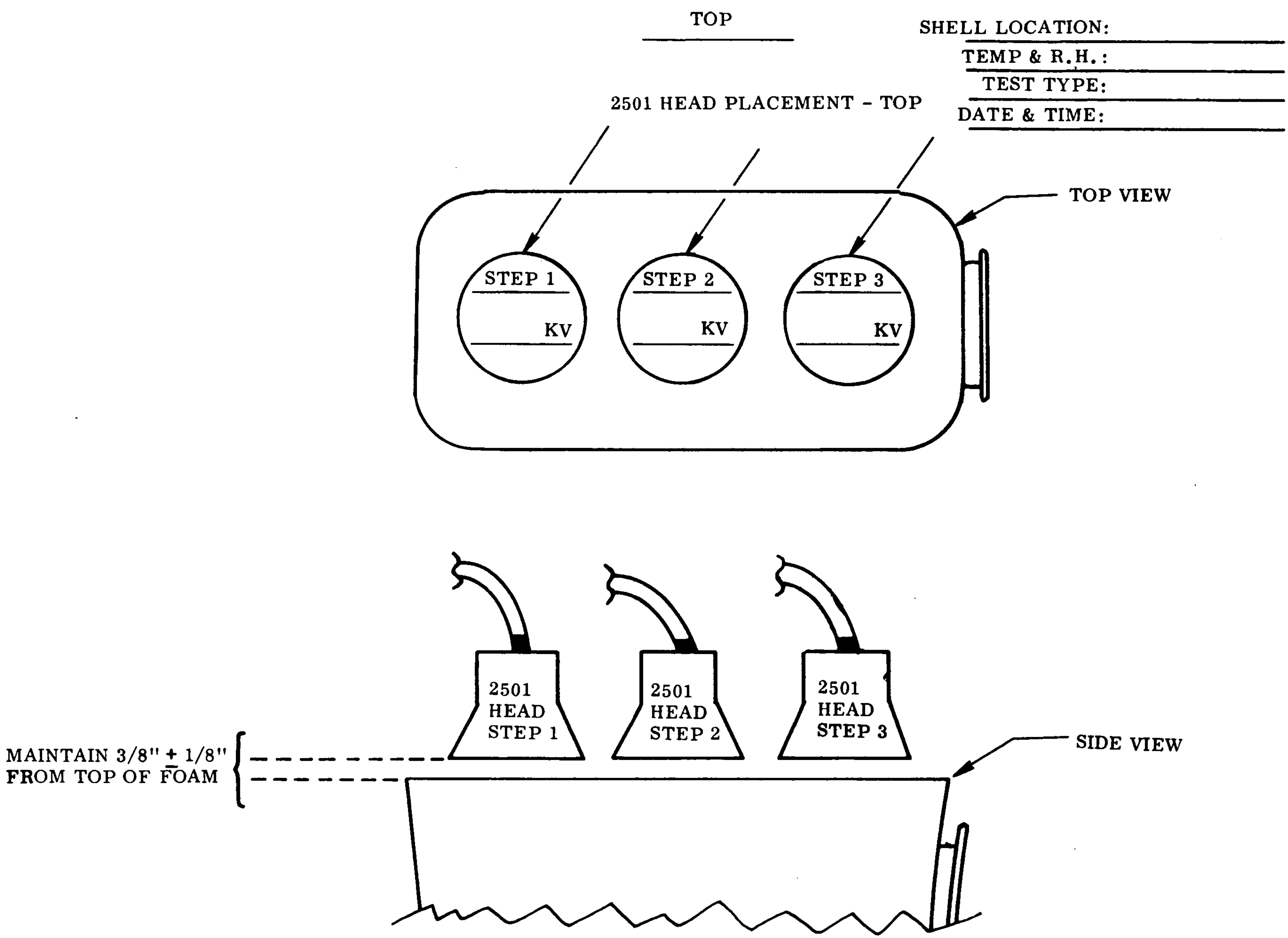


Figure 5-8. E8 Foaming Test Top Measurements

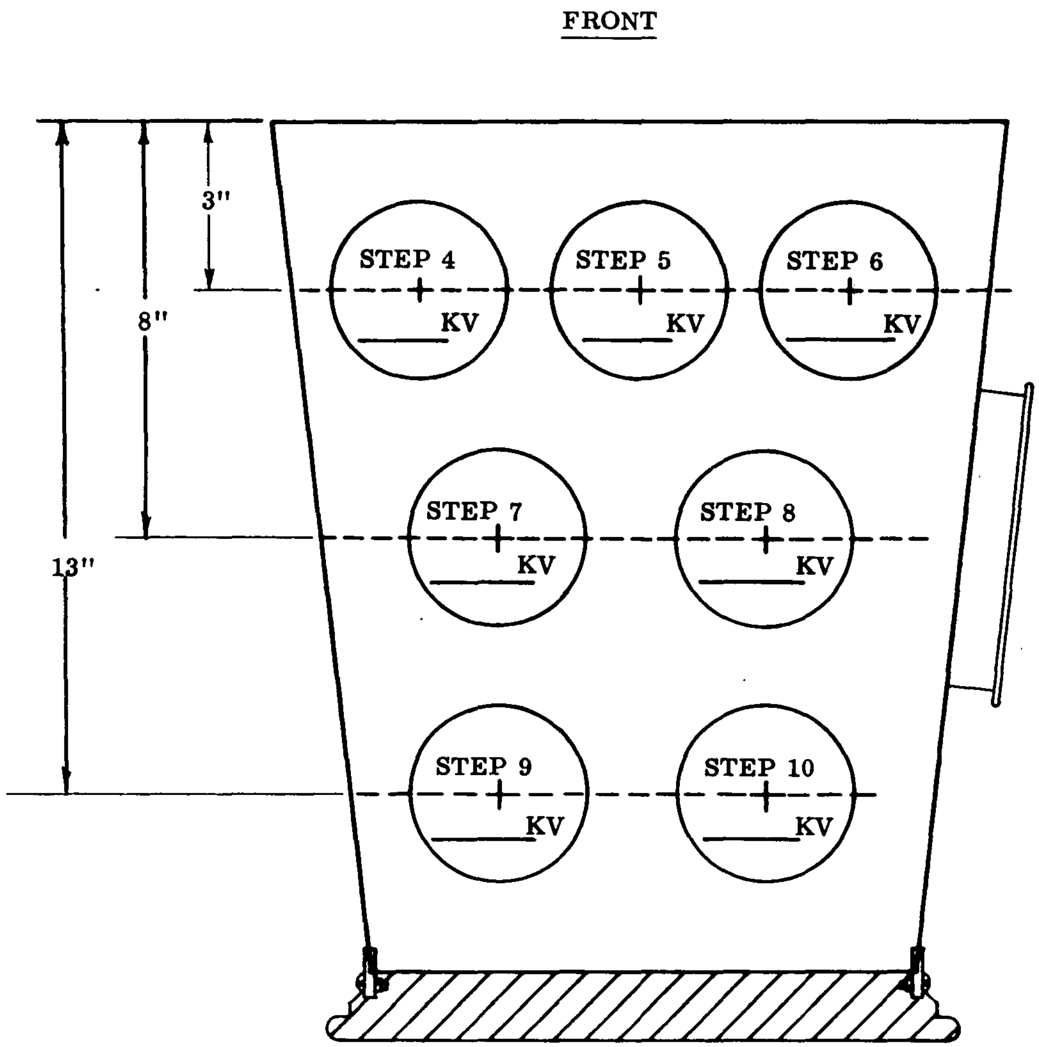


Figure 5-9. E8 Foaming Test Front Measurements

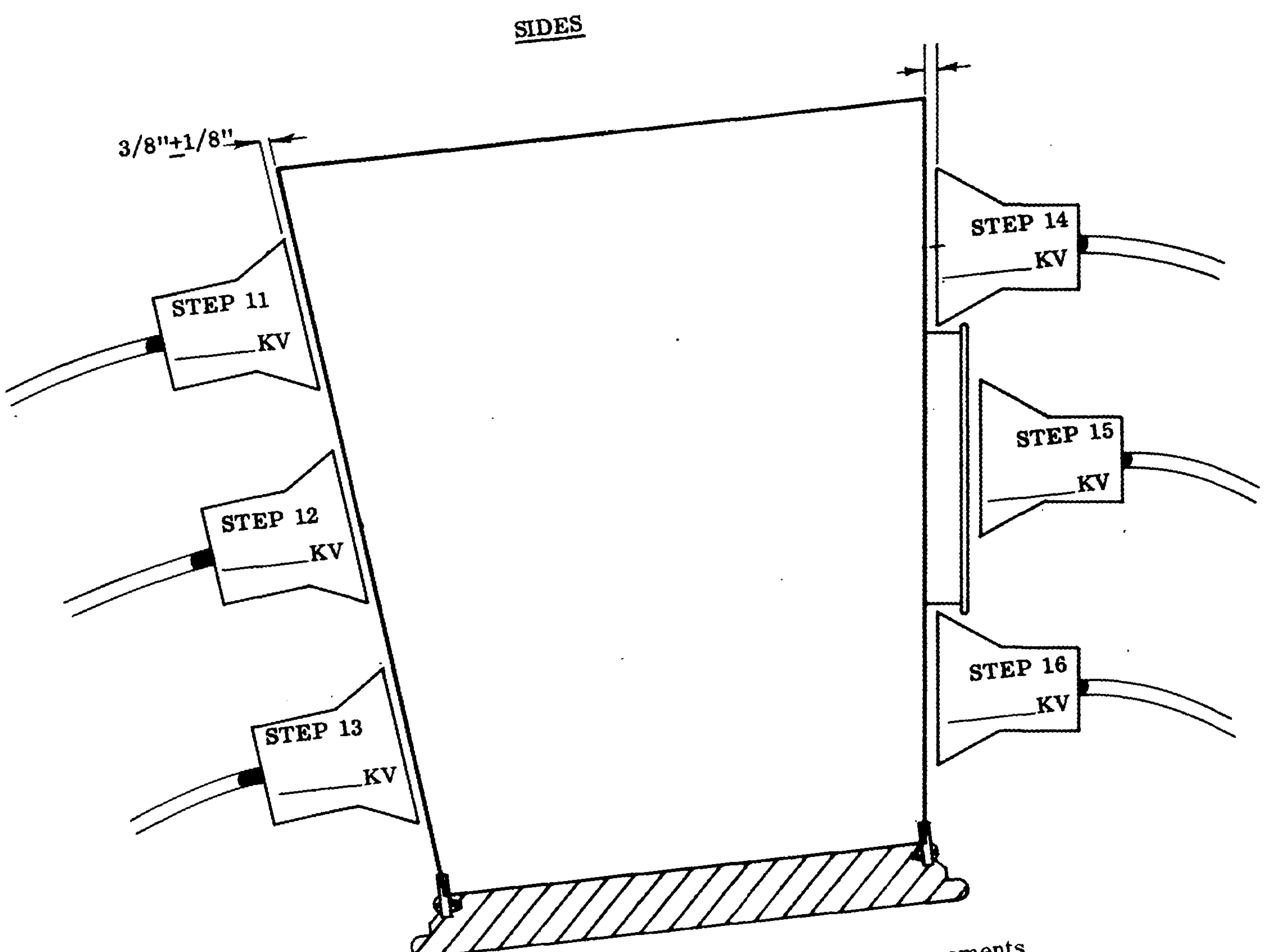


Figure 5-10. E8 Foaming Test Side Measurements

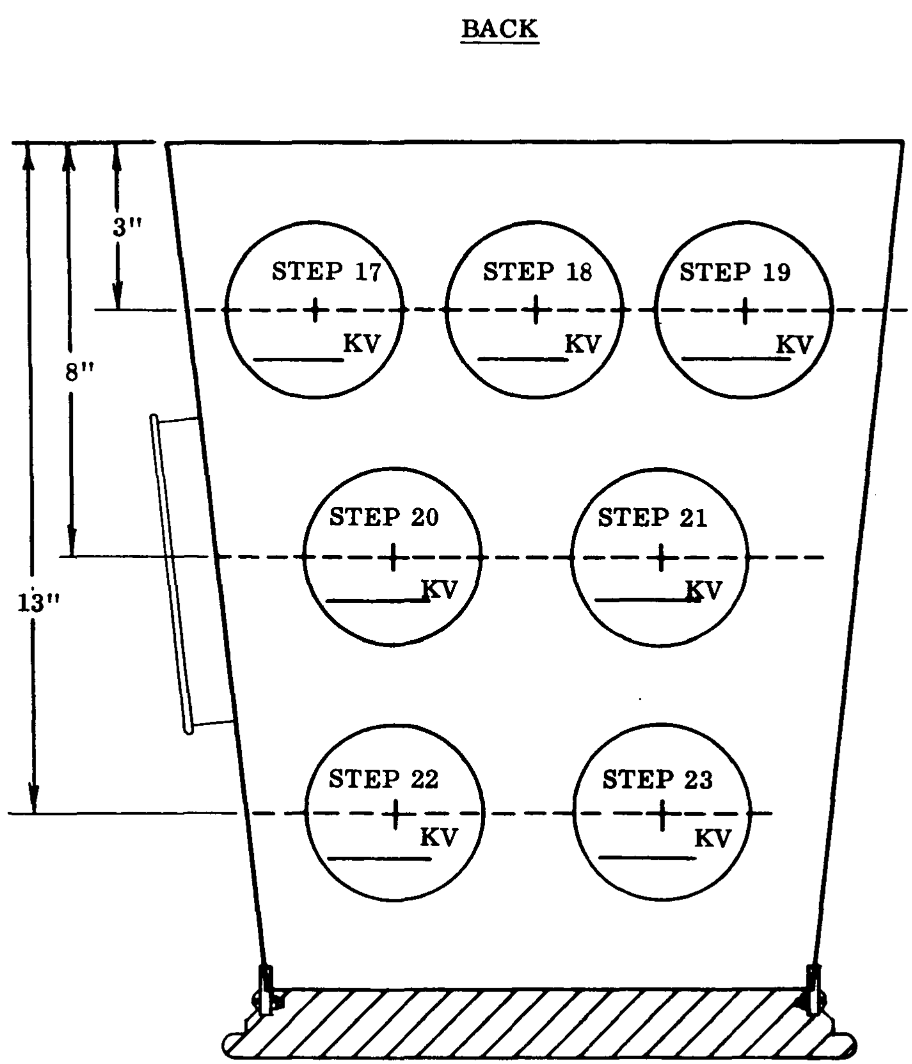


Figure 5-11. E8 Foaming Test Back Measurements

At this time, the top plate (3/8-inch thick aluminum) was knocked off, leaving the aluminum foil vapor barrier exposed. Voltage measurements taken at this point are listed in Table 5-1. After taking these measurements, foam was poured into the vapor barrier and a wax coated wood lid was clamped securely over the top (Figure 5-7). During this curing period, electrostatic potentials were negligible.

After a 20-minute curing period, the top plate was knocked off and measurements were taken. These readings are also listed in Table 5-1. While making these measurements, a discharge occurred between the top edge of the vapor barrier and the 2501 instrument head. The initial reading was considerably higher than the 8kv listed in the table. The spark from the conductive vapor barrier discharged a high percentage of the charge that was initially present, reducing the potential to 8 kv.

The module 2 configuration was identical to module 1 except the wood mold was not used on the sides. The test procedure was repeated on module 2. The results were identical except for the small variations noted in Table 5-1. It was noted that any tear-off or movement of the foam spillage created static readings up to 8 kv.

While working with the second module, an 8-inch length of theralite igniter cord was removed from the system, stripped of its fiberglass tape cover, and placed into freshly poured foam. After approximately five minutes of curing, the cord ignited and was totally consumed. This test demonstrated that if any part of the igniter cord itself comes into contact with the curing foam, ignition is highly possible.

5.3.5 RECOMMENDATIONS

The feasibility of the theory that an electrostatic discharge induced inadvertent functioning of the E8 unit has been established. Potentials were measured which were more than sufficient to discharge across the 3/8-inch gap observed between the bare wire junction and the aluminum vapor barrier edge. In fact, a discharge occurred during testing.

Since high electrostatic potentials are generated during the top plate removal step of the foaming operation, it is recommended that antistatic measures be employed during this operation.

One approach would be to spray a fine mist of water on the top of the canister during the removal of the second top cover plate. This spray would not saturate the components of the canister as the vapor barrier seals the canister during the first foaming operation. Another approach would be to use static neutralizers (air stream of ions) or nuclear static eliminators.

Another approach would be to apply a surface to the top plate which would not adhere as intimately to the cured foam. A lubricated surface may suffice.

It is also recommended that a test program be implemented to determine if these antistatic measures would be successful.

Table 5-1. Values for Voltages Measured

(Readings Measured in Kilovolts)

	Module 1		Module 2	
Reading * Location	First Top Plate Removal	Second Top Plate Removal	First Top Plate Removal	Second Top Plate Removal
1	.8	7.5	.6	7.0
2	.6	8.5	.8	8.5
3	1.0	9.5	.8	9.0
4	.3	.3	.4	.6
5	.3	.3	.5	.5
6	.4	.3	.6	.6
7	.2	.3	.3	.5
8	.2	.25	.3	.4
9	.25	.3	.4	.4
10	.2	.2	.3	.4
11	.3	.2	.2	.3
12	.2	.2	.2	.3
13	.2	.2	.2	.25
14	.3	.2	.3	.3
15	1.2	1.8	2.5	2.8
16	.2	.2	.3	.3
17	.3	.2	.2	.3
18	.2	.2	.3	.35
19	.2	.2	.2	.3
20	.2	.2	.3	.35
21	.2	.2	.2	.35
22	.2	.2	.25	.2
23	.15	.2	.2	.2

* See Figures 5-8 to 5-11.

5.4 INVESTIGATION REPORT OF AN INADVERTENT FUNCTIONING OF AN XM15 CLUSTER DURING MANUFACTURING

5.4.1 GENERAL

An XM15 CS chemical agent canister cluster functioned prematurely during the assembly process at the Brunswick Manufacturing Facility, Sugar Grove, Virginia, Saturday morning, October 19, 1970. At the request of Edgewood Arsenal an on-site investigation was conducted. The results of this investigation are presented in the following paragraphs.

5.4.2 SYSTEM DESCRIPTION

The XM15 cluster, as shown in Figure 5-12, is designed to disperse XM16 CS canisters which in turn disperse CS gas (tear gas). The cluster is deployed by dropping it from a helicopter or small plane and functions before reaching ground level. The cluster consists of 8 modules, each containing 33 canisters. In the normal firing sequence the two end modules are expulsed by black powder bags (expulsion charge), in turn igniting the XM16 canisters. After 0.5 seconds the next two outermost modules are dispersed. The sequence continues for the third and fourth pair of modules. Initially, each side is actuated simultaneously by an XM721 mechanical time fuze (refer to Figure 3-4). The timer ignites a delay fuze line which initiates each half of the cluster via a pellet in each small junction block shown in Figure 3-4. Each pellet ignites two delay fuze lines (redundant to increase reliability) which burn toward the end of the cluster, igniting two pellets in a large junction block. Each pellet then ignites four delay fuze lines, each connected to an igniter which ignites the black powder bag (expulsion charge). The delay fuze lines from the large junction blocks burn back toward the center of the cluster. The successive delay fuze lines are 0.5 seconds longer than the previous one, sequentially igniting the black powder bag in each module with the proper timing starting from the outermost module and going toward the center.

The following changes had been incorporated as the results of Edgewood and MT&R spark ignition tests:

- Aluminum junction blocks were used in lieu of Lexon junction blocks.
- Conductive cements are used to electrically bond the delay fuze to the junction blocks.

5.4.3 DESCRIPTION OF THE INCIDENT

According to statements from Brunswick personnel, it is believed that the accident happened in the manner described in the following paragraphs.

One-half of an XM15 cluster functioned prematurely and apparently caused one-half of another cluster and numerous XM16 canisters to function. When the XM15 cluster functions, the XM16 canisters are dispersed in all directions. Apparently, these canisters ignited the other XM15 cluster and a stock pile of XM16 canisters located in area B in Figure 5-13.

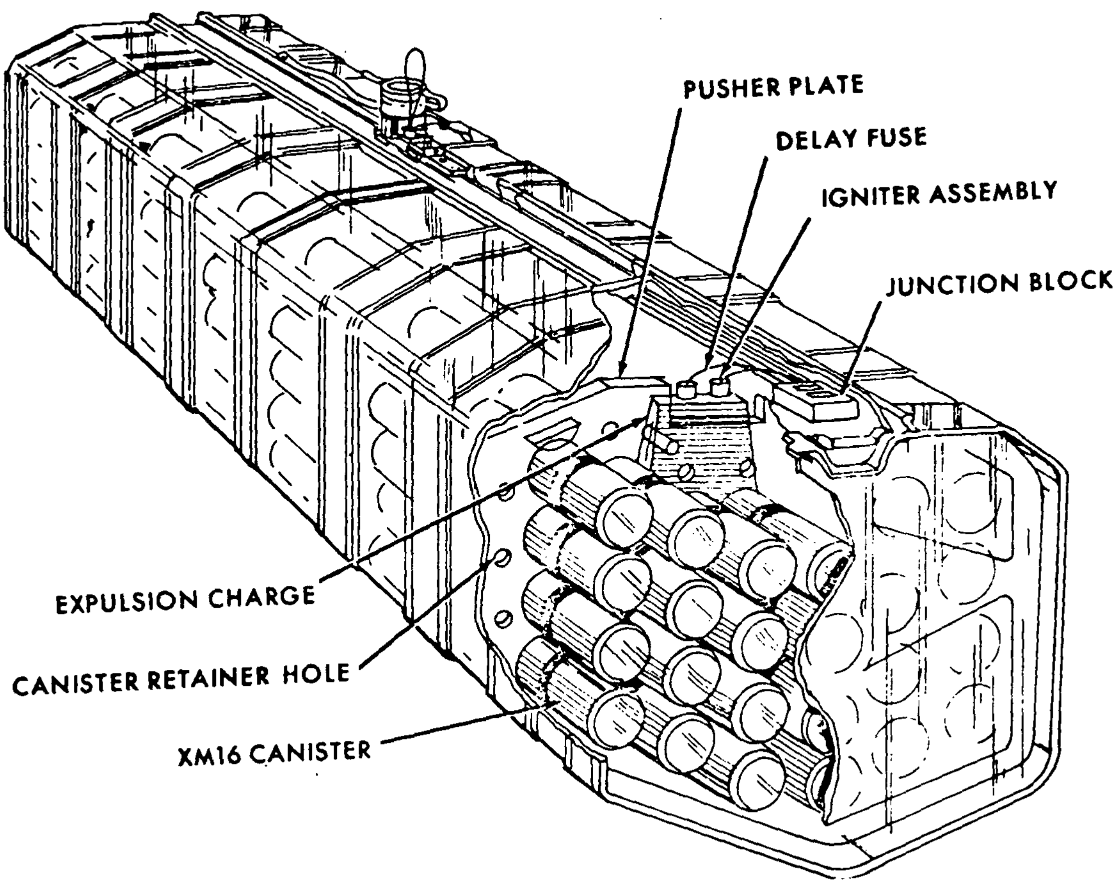


Figure 5-12. XM15 Canister Module, Cross-Section View

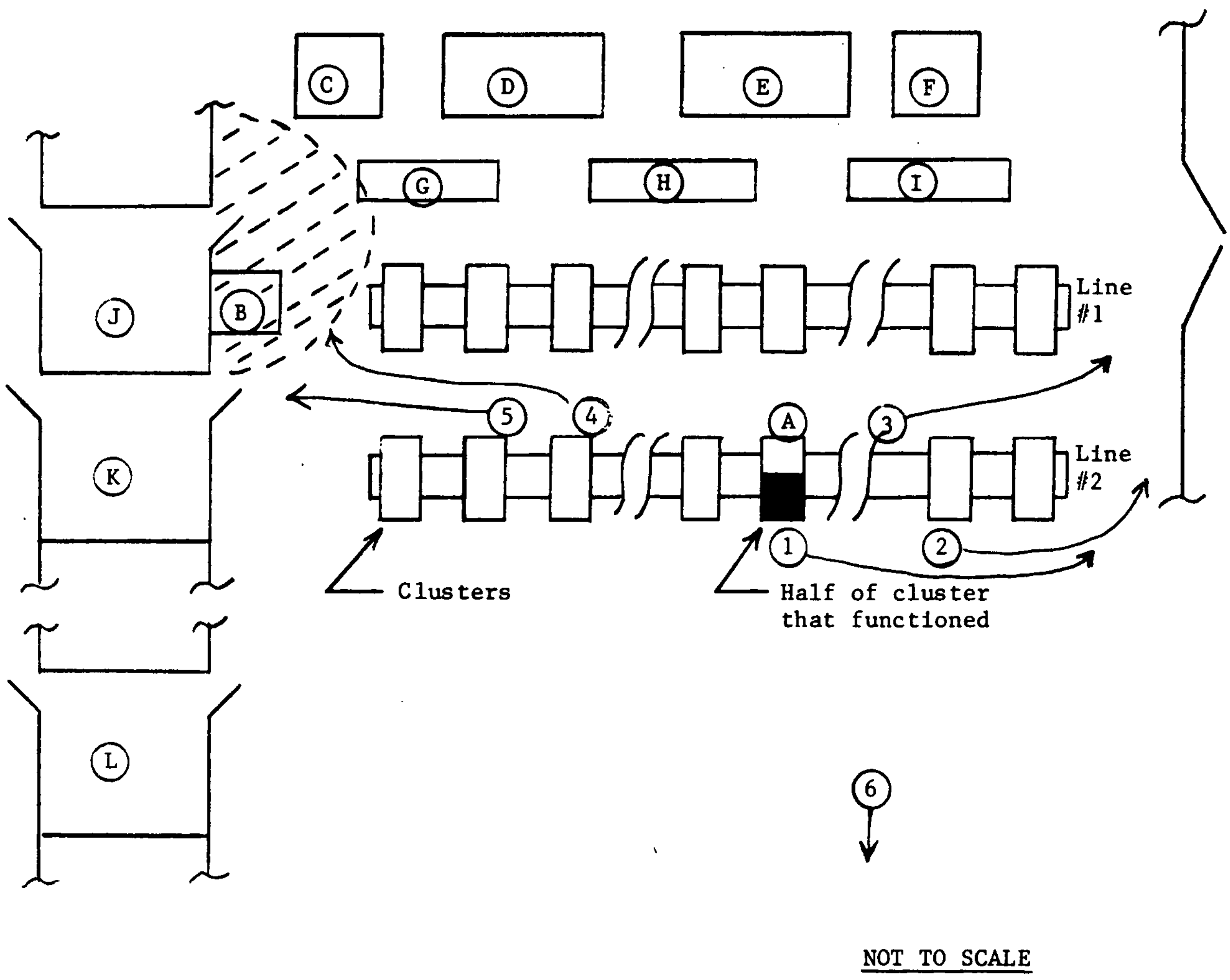


Figure 5-13. Physical Layout of Facility

The physical layout of the pertinent areas of the facility is shown in Figure 5-13 for reference. The two clusters that functioned were found within the "dashed" area of Figure 5-13, and functioned XM16 clusters were found throughout the facility. The two clusters originated from area A.

The excess delay fuze line was being trimmed from inside of the junction blocks when the incident occurred. This step is necessary since it is not feasible to precut and install the delay fuze lines to the precise length required. This process occurs prior to ignition pellet installation , so pellets were not in the clusters that functioned. A worker simply cuts the delay fuze to the proper length (inside the junction blocks) with an X-acto knife and then removes the excess with metal tweezers. Also, the center core of the delay fuze must be exposed.

Trimming of the delay fuze lines was being conducted on the clusters shown on assembly line number 2 (Figure 5-13). Workers 1 and 2 were facing line 2. Workers 3, 4, and 5 were working the other side of line 2. As Worker 1 either approached, touched, trimmed or had finished trimming the cluster in area A, the cluster functioned. Worker 1 could not remember at what point in the trimming sequence a boom was heard. Upon hearing a boom, Worker 1 evacuated through the doors to the right as shown in Figure 5-13. Worker 1 received a small burn on one wrist. The other workers confirmed that the clusters in front of Worker 1 functioned. They heard a boom and saw a small fireball (black powder bag ignition). Everyone's prime concern was to evacuate--no one was really interested in staying around and taking notes. Workers 2 and 3 evacuated through the doors as shown to the right in Figure 5-13. A burning object did pass from left to right in front of them before they reached the door. Workers 4 and 5 evacuated to the left side of the facility but did not see any burning objects in front of them as they left line number 2, which indicates the XM16 canisters in area B functioned later. The shift foreman, 6, was standing at the opposite end of the room, and before evacuating he heard four equally spaced booms. This indicates that one-half of a cluster functioned in its normal sequence.

The maintenance man, who cleaned the facility afterward, stated that most of the debris along with the two expended clusters was found within the dashed area as shown in Figure 5-13. He also stated that a small fire occurred in area C which actuated the sprinkler system along the wall adjoining the individual work rooms J, K, etc. The cleanup crew could not distinguish which parts of the debris were directly involved in the incident since some unassembled parts were included. They did observe that assembly line 2 had a vacant spot and both of the clusters must have originated at that point since it could not be determined where the second cluster originated. XM16 canisters that had functioned were found throughout the facility.

The facility was cleaned and painted where required. The two expended clusters along with the other clusters were moved to another building for storage.

Information could not be obtained from a visual inspection of the two expended clusters since all that remained was the center shell and the nonfunctioned half.

From the sketchy details and lack of visual evidence, the possibility of determining the cause of the incident is very slim, if not impossible. If it is assumed that Worker 1 made contact with the delay fuze/junction block, then two possible initiating mechanisms could exist--electrostatics and friction.

The manufacturer of the delay fuze states that his personnel have ignited the fuze by striking the ignition composition with a sharp point. Brunswick tried various techniques of igniting the composition by striking it with sharp objects, pulverizing it, etc., but could not cause ignition. But since many lines have been cut in the project, this type of ignition must have a low probability of occurrence.

The possibility of electrostatic ignition is discussed in the following paragraphs.

5.4.4 FACILITY CONDITIONS

The facility has a conductive floor that is connected to ground, and all personnel are required to wear conductive shoes and clothing that is not susceptible to electrostatic charge buildup. Prior to entering the facility a conductive meter is used to measure the conductivity through the shoes. Personnel stand on two plates--one foot on each-- and press a lever with one hand which connects them into the circuit, thereby measuring the total conductivity. This ensures (provided their shoes are in good contact with the floor) that all personnel are grounded at all times since the floor is grounded. The doors stay open and the outside air is allowed to circulate freely throughout the building. There are no humidity controls in the main processing area.

The humidity is kept at a high level in those process areas (small rooms) where sensitive materials are handled. The floors are kept wet, thereby increasing the humidity. A wet-dry bulb is used to measure the humidity. All tables, chairs, benches, etc., are conductive and grounded. All process machinery is well grounded.

The workers also wear grounded wrist bracelets. All personnel are required to wear safety glasses.

The humidity on the day of the incident was between 50 and 60 percent.

5.4.5 ELECTROSTATIC MEASUREMENTS

The scope of the investigation was extended to determine the presence of electrostatics throughout the facility and process areas, since it is possible for a residual electrostatic charge to be built into the XM15 cluster. During the investigation, Custom Materials, Inc.'s, static meter, Model CMI-7777, was used to measure for local electrostatic potentials. This meter measures the potential between an object and the meter or the potential of the electrostatic field at the meter. All measurements were taken with the meter two inches away from the object to be measured for electrostatic potential. Measurements were taken in all areas of the facility and during each process operation. Significant electrostatic potentials were detected in the following five areas of operation:

- Sealing wire installation
- XM16 canister installation
- Cluster sealing operation
- Igniter assembly installation
- Loading the XM16 igniter fuze tube

5.4.5.1 Sealing Wire Installation

A sealing wire is installed on each individual cluster shell. This is done by wrapping number 18 AWG copper wire around the outside of the open end (the shell is bucket shaped) and passing a current through the wire until it slightly fuses into the shell. Electrostatic potentials ranging up to 10,000 volts were measured on the inside bottom surface of the cluster shells before, during and after wires were installed. The wire installation takes place in areas D and E as shown in Figure 5-13. Cluster shells are stored in hampers or areas C, F, G, H, and I as shown in Figure 5-13.

5.4.5.2 XM16 Canister Installation

XM16 canisters are "sandwiched" between pusher plates and shell covers in work room K (Figure 5-13). The shell cover is placed on a conductive table top which is connected to ground. The XM16 canisters are then placed bottom down on the shell cover and the pusher plate is installed on the top of the assembly. To remove the assembly from the table, it must be slid to the end of the table and then picked up. During the removal process 7,000 to 10,000 volts are generated on the bottom side of the shell cover. The fact that the table top is conductive and grounded does not prevent the generation of electrostatic charges when the insulator (shell cover) is moved across and then separated from the table top.

The canister assemblies are stored in area B (Figure 5-13) in stacks of four. Potentials up to 4,000 volts were measured on the assemblies at the top of the stacks. The top assemblies were removed and potentials of up to 2000 volts were measured. The canister stacks are moved (by hand) from area B to room J where they are installed into the cluster shells which have been moved (by hand) into room J from hampers G and H

5.4.5.3 Cluster Sealing Operation

The center shell assembly, consisting of two cluster shells back to back, is placed into the XM15 cluster sealing fixture. The black powder bag and expulsion pads are placed into the shell followed by the XM16 assembly. A cluster shell is then placed into the center shell (telescopic arrangement). A current is again passed through the sealing wire fusing the two shells together, thereby sealing the unit. This process continues until eight modules have been attached, thereby forming the complete XM15 cluster.

Electrostatic potentials ranging from 1 to 4 kv were measured on the inside bottom surface of the cluster shells prior to insertion into the sealing fixture. During the sealing process potentials up to 20 kv were measured on the outside surface of the cluster assembly. However, most of the charge producing this potential bleed off within a few minutes.

Upon completion of the assembly of each XM15 cluster, it is hand carried to the end of an assembly line where it is stored until the next process (igniter assembly installation). The assembly at this point had a potential of between 2 and 4 kv. This charge does bleed off after several hours.

5.4.5.4 Igniter Assembly Installation

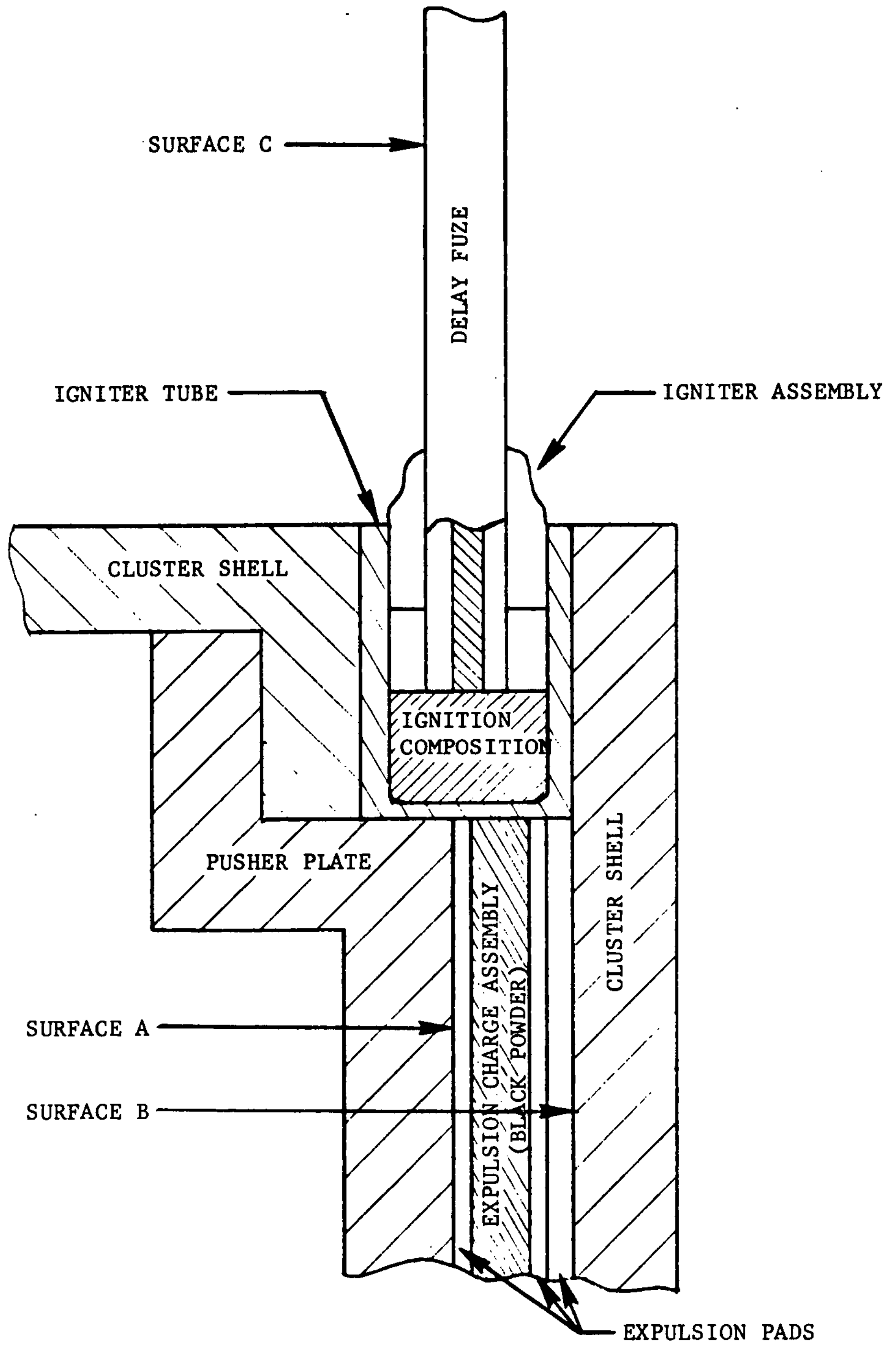
The XM15 clusters as received from work room J (Figure 5-13) are placed on wooden frames which in turn are placed on an assembly line (a frame line with grounded rollers). The igniter assemblies, consisting of delay fuze, igniter tube, ignition composition, etc. (refer to Figure 5-14) are then installed. The delay fuze extends straight upward. A thin coating of RTV is applied to the fuze trough and the junction blocks are placed in position.

Measurements were made along the trough, at the junction blocks and at the ends of the delay fuze lines. Most of the delay fuze lines had a potential of about 200 volts. The lines were grounded but the voltage reappeared after the ground was removed. This indicates that voltage is being inducted into the delay fuze line. The potential along the trough ranged from 200 volts to 3 kv. The 3 kv reading occurred over a large junction block.

5.4.5.5 Loading the XM16 Igniter Fuze Tube

The fuze system for XM16 canister consists of an igniter fuze tube, ignition composition, time fuze, ring stiffener, fuze retainer and black powder. The ignition composition is machine loaded into the igniter fuze tube. The tubes are then placed upright in a conductive slotter tray. The tray is moved to a small conductive top table where the time fuzes are inserted into the tubes. Plexiglas barriers are between the workers and the loaded tubes. The worker reaches, with both hands, around the plexiglas to install the time fuze. All workers wear conductive wristlets which are connected to ground. This operation takes place in room L (Figure 5-13). The floor is kept wet to maintain a high humidity.

Electrostatic potentials were found in three locations. The igniter fuze tubes are stored in a conductive bucket and a composite charge representing about 2 kv was measured. However, less than 50 volts were found on the individual tubes, and this would be removed when the worker picks it up for loading. The plexiglas had about 200 volts on the outer surface. A composite potential of 200 volts was measured on the loaded tubes in the storage tray. However, a potential could not be detected on the individual loaded tubes.



NOT TO SCALE

Figure 5-14. Cross-Section of Igniter Assembly and Expulsion Charge Assembly

5.4.5.6 Other Measurements

Measurements were made in other areas and process steps such as loading the black powder bags, loading the XM16 canisters, etc., but significant potentials were not measured. The outside surfaces of all of the completely assembled clusters were checked but potentials were not present.

Clusters which had been processed up to the delay fuze trimming operation were measured for electrostatic potentials; however, none were found.

5.4.6 POSSIBLE ELECTROSTATIC CAUSES

The cause of the incident could have been the results of an electrostatic discharge. However, there is insufficient evidence for one to draw that conclusion. Since the following electrostatic potentials were measured it is conceivable that the incident was caused by electrostatics:

- 200 volts on the delay fuze (surface C in Figure 5-14)
- Up to 10 kv on the inside of the cluster shell (surface B in Figure 5-14)
- Up to 4 kv on the top of the pusher plate (surface A in Figure 5-14)
- Up to 3 kv along the trough of the cluster (fuze train fits into the trough)

With the inside surfaces of the XM15 cluster containing electrostatic charges, an electrostatic field is produced. This will induce voltage into the conductive parts of the cluster, primarily the fuze train. However, potentials could not be found on any units after the delay fuze lines were installed in the junction blocks.

With the following assumptions and conditions it is feasible that the delay fuze lines ignited:

- An electrostatic field was present and sufficient to induce a large voltage (approximately 10 kv) into the delay fuze lines.
- The worker started at the large junction block (end block).
- The worker's X-acto knife contacted the center core or powder from the center core and a spark occurred.
- The spark contained sufficient energy to ignite the powder or center of the delay fuze. Tests have revealed that the center core will ignite between 100 and 200 μ joules. The capacitance as calculated between an X-acto knife and the inside of the block is approximately 2 $\mu\mu$f. This means that approximately 10 kv must be present on the fuze/block ($E = 1/2\ CV^2$).
- The other three delay fuze lines ignited either from the heat of the spark, the heat from the first lines or the heat of the black powder bag.

If the worker started at the small junction block and if the output delay line ignited (line from the small block to the large block), the heat from this line could have ignited other delay fuze lines (this has occurred one time during spark ignition tests). In this case it is conceivable, but not likely, that one of the inward modules ignited first blowing the remaining modules away from the clusters. However, this is inconsistent with the statement of the shift foreman, unless all of the lines ignited and the system functioned in reverse which is not likely.

Another possibility, although remote, is that a pusher plate (Figure 5-14) had a potential in excess of 5 kv and was in contact with the igniter tube. The bottom side of the igniter tube has a dielectric strength of approximately 5 kv (if the smaller tolerance exists). Therefore, since the ignition composition is conductive, a spark could have occurred as the worker came in contact with the fuze train.

5.4.7 MANUFACTURING CHANGES SINCE THE INCIDENT

A ground wire is now attached to the delay fuze lines before the trimming operation begins. This will eliminate the possibility of ignition due to a voltage occurring or being induced on the delay fuze, thereby preventing the most likely ignition cause due to electrostatics.

The assembly lines have been relocated to provide for faster evacuation.

5.4.8 RECOMMENDATIONS

Since electrostatic potentials were measured in several operations it is recommended that antistatic measures be employed in these operations. The two main areas are the sealing wire installation and the installation of the XM16 canister assembly. The use of an aerosol, antistatic spray, is recommended; however, care must be taken to ensure that the fuze orifice assembly of the XM16 canisters are not saturated since this could impede ignition of the canisters. One type of antistatic spray, "Statikil," has been used on the cluster shells (surlyn), but Brunswick stated that this brand caused the surlyn to deteriorate. Brunswick did state that they would try various other types of antistatic sprays to determine if one could be used.

Another approach would be to wipe the surlyn with a damp cloth or use static neutralizers (air steam of ions) or nuclear static eliminators.

It is also recommended that a test program be implemented to determine if the delay fuze line can be ignited by the trimming process.

ATTACHMENT A

XM15 FUSE TRAIN SUBSYSTEM TEST PROCEDURE

5.A.1 PURPOSE

This procedure outlines the steps for performing tests to determine end-to-end electrical pulse discharges to XM15 fuse trains.

5.A.2 TEST EQUIPMENT

The following test equipment will be utilized for this testing:

- Fluke High Voltage Power Supply, Model 410B
- 0.002, 0.01, 0.02, 0.05, 0.1, and 1 μ F 10 KVDCW Capacitors
- Fluke Voltage Divider, Model 80E
- Spark Gap Test Fixture

5.A.3 TEST PROCEDURE

Testing will be conducted as follows:

a. Verify that the high voltage supply is off.

b. Set up the test equipment and fuse train as shown in Figure 5-1.

c. Turn on the high voltage power supply.

d. In the approximately 50 seconds between steps, advance the output switches in 100 volt increments, closing the spark gap 50 seconds after each increment up to 1 kv.

e. After reaching the 1 kv level, follow the procedure in step d using 500 volt increments until reaching 10 kv.

f. Return the power supply high voltage output switches to zero and turn off the supply.

g. Record observations and comments concerning the results of the test on the data sheet.

ATTACHMENT B

ELECTROSTATIC DISCHARGE SENSITIVITY OF THE XM15 FUSE TRAIN ASSEMBLY

The data sheets presented in this attachment present the raw data of the spark discharge ignition sensitivity test in an end-to-end configuration. (Reference paragraph 5.2 for more details.)

DATA SHEET

SAMPLE NO. 1

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE / HUMIDITY / DATE OBSERVATIONS AND COMMENTS
1	XM15 Closed Loop	1	100	0.005	No Ignition
2	XM15 Closed Loop		1K	0.5	Ignition

SAMPLE NO. 2

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 54° F · HUMIDITY 90% · DATE 2/3/71 OBSERVATIONS AND COMMENTS
1	XM15 Open End	.002	9.9kv	N/A	200V Increments - No Ignition

SAMPLE NO. 2

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 54° F / HUMIDITY 90% / DATE 2/3/71 — OBSERVATIONS AND COMMENTS
1	XM15 Closed Loop	.002	0-6kv	.036Max.	500V Increments - No ignition
2	XM15 Closed Loop	.002	6.5kv	.042	Arc at Test Fixture Oscillated Ignition Occurred on 4th Arc

SAMPLE NO. 3

DATA SHEET

TEST NO.	TEST CONFIGURATION	VALUE OF CAPACITANCE (μf)	VOLTAGE LEVEL (VOLTS)	ENERGY $1/2CV^2$ (JOULES)	TEMPERATURE 54^oF / HUMIDITY 90% / DATE 2/3/71 — OBSERVATIONS AND COMMENTS
1	XM15 Closed Loop	.002	0-9kv	.081Max	200V Increments - No Ignition
2	XM15 Closed Loop	.01	0-8kv	.32 Max	200V Increments - No Ignition
3	XM15 Closed Loop	.02	0-6.2kv	.38 Max	200 V Increments - Ignition Occurred at 6.2 kv

SECTION 6
RECOMMENDATIONS

6.1 INTRODUCTION

Based on the analysis of the data obtained during Phase I and Phase II of the electrostatic vulnerability studies of the XM15/XM165 and E8 systems, modifications have been suggested to decrease the units' vulnerability. Some of these recommendations have been developed within earlier sections of this report or in previously distributed components of the report. For the convenience of the reader, all recommendations are repeated in this section.

6.2 MODIFICATIONS TO XM15 JUNCTION BLOCKS

6.2.1 JUNCTION BLOCK MATERIAL

When this program was begun a modification was suggested by Edgewood Arsenal personnel that the junction block (see Figure 3-4) be changed from an insulating material (lexan) to a conducting material. Since the delay fuses are sheathed in lead (a conductor), the conducting junction block would electrically connect all components in the fuse train, provided the resistance at the fuse-junction block interface remained low (in good electrical contact). Such a system is necessarily equipotential at all points; hence, sparking could not be induced between any two points.

The junction block material was initially specified to be lead to prevent corrosion as a result of galvanic action between dissimilar materials. Galvanic action proceeds via an interstitial medium which acts as a vehicle to transport the ions from one material to the other. In the absence of any such medium, corrosion cannot occur. Because the entire fuse train is encapsulated in RTV-60, there is no way for an external material to seep into the fuse-junction block interface. The RTV-60 and its primer are not capable of maintaining a significant ion current; thus, if the junction is clean there is no danger of galvanically-induced corrosion between dissimilar material. For this reason and machinability properties, aluminum was suggested for the junction block material.

6.2.2 CONDUCTIVE ADHESIVE

To ensure a good electrical connection between the fuses and junction blocks, it was suggested that conductive epoxy be applied to their external interface. This procedure proved very effective in tests (see paragraph 3.4.5) to reduce ignition sensitivity. The long-term (months or years) stability of the junction is in doubt. It was noted that junctions expoxied during normal manufacture appeared to have deteriorated at the epoxy-lead interface, forming an insulating layer. This characteristic is under study.

Several of the fuses from the Thiokol assembled unit were not attached with conductive cement. This should be remedied, as it may contribute to the low ignition sensitivity observed with those units.

6.2.3 COATED PELLETS AND FUSE ENDS

Faint sparks were visually observed in the pellet cavity in a junction block subjected to pulses of several joules. It was theorized that the increased surface area of a flaking or powdering pellet or fuse end would increase its susceptibility to initiation from low energy sparks. It was suggested that coating of the pellet and fuse ends may alleviate any flaking and hence reduce the ignition sensitivity. Tests of both conductive and nonconductive coatings were inconclusive. The tests indicated that the ignition sensitivity to heat was thereby reduced so greatly that the pellets failed to normally function. These results are consistent with either the pellets having been desensitized by the coatings or the pellets having previously been rendered inoperable as a result of improper storage.

6.3 MODIFICATIONS TO THE XM15 FUSE TRAIN

To ensure the end-to-end conductivity of the XM15 fuse train and the low resistance connection of all components within the fuse train, it is suggested that a single flexible buss bar be attached with conductive epoxy to all components before application of the RTV during fabrication. The buss bar, a flat braided line or a copper or brass sheet approximately one-half inch wide, would extend the entire length of the fuse train and be in positive electrical contact with all components of the fuse train.

This configuration would provide a low inductance (since flat) and low resistance buss line in parallel with all components of the equivalent circuit of the remainder of the unit. Thus a current pulse applied to any point in the fuse train would dissipate itself through the buss line, thereby bypassing the critical junctions in the vicinities of the fuse ends and pellets.

The recommended positioning of the buss line is shown in Figures 6-1 and 6-2. Note that positive contact is made to each of the four junction blocks, the four pairs of upper and lower separators, and all fuses at a location on the fuse other than the connection to the junction blocks. Figure 6-1 is the unmodified fuse train; Figure 6-2 indicates the suggested modifications.

A requirement of such a system is that the sections of the cluster will continue to effectively separate; i.e., the buss line should either have a very low longitudinal tensile strength or the adhesion of the buss line to the fuse train should be easily breakable. The latter capability is well within the range of most conductive cements.

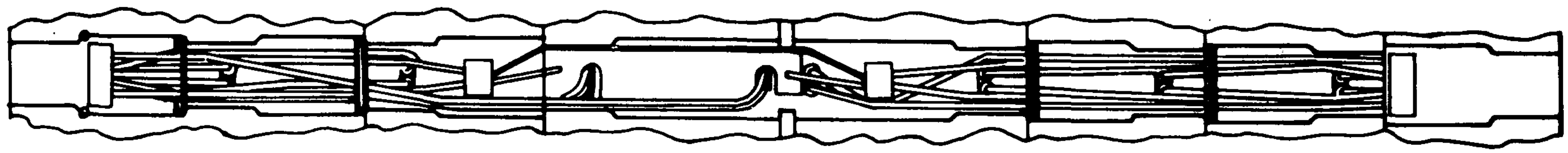


Figure 6-1. Unmodified Fuse Train

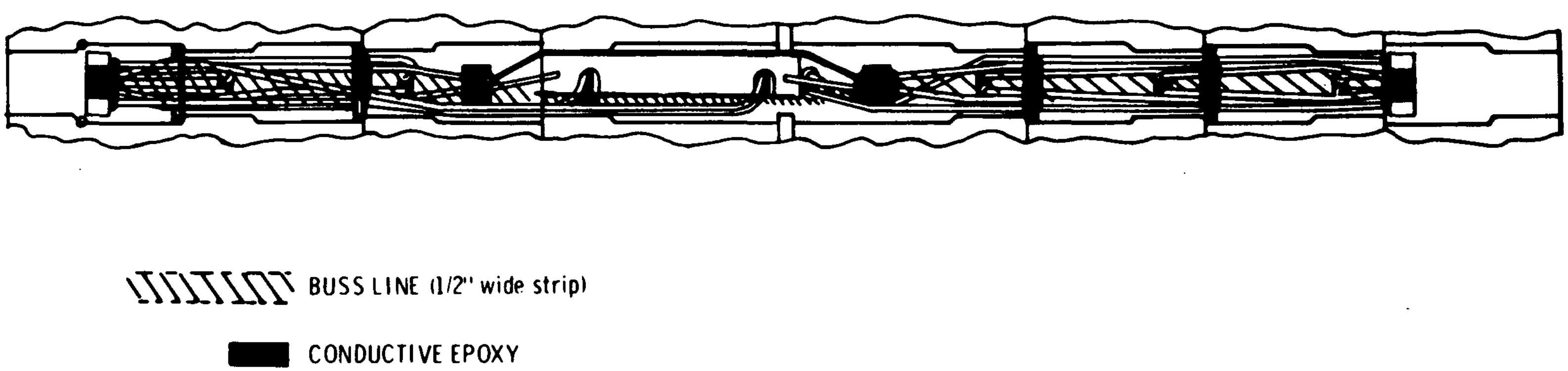


Figure 6-2. Buss Line Modification to Fuse Train

6.4 FABRICATION PROCEDURE RECOMMENDATION

These recommendations are made based on surveys conducted at the manufacturing facilities.

6.4.1 E8 FOAMING OPERATION

The E8 foaming operation investigation is described in paragraph 5.3.

Since high electrostatic potentials are generated during the top plate removal step of the foaming operation, it is recommended that antistatic measures be employed during this operation.

One approach would be to spray a fine mist of water on the top of the canister during the removal of the second top cover plate. This spray would not saturate the components of the canister as the vapor barrier seals the canister during the first foaming operation. Another approach would be to use static neutralizers (air stream of ions) or nuclear static eliminators.

Another approach would be to apply a surface to the top plate which would not adhere as intimately to the cured foam. A lubricated surface may suffice.

It is also recommended that a test program be implemented to determine if these antistatic measures would be successful.

6.4.2 XM15 CLUSTER FABRICATION

The SM15 cluster fabrication investigation is described in paragraph 5.4.

Since electrostatic potentials were measured in several operations, it is recommended that antistatic measures be employed in these operations. The two main areas are the sealing wire installation and the installation of the XM16 canister assembly. The use of an aerosol, antistatic spray, is recommended; however, care must be taken to ensure that the fuze orifice assembly of the XM16 canisters are not saturated since this could impede ignition of the canisters. One type of antistatic spray, "Statikil," has been used on the cluster shells (surlyn), but Brunswick stated that this brand caused the surlyn to deteriorate. Brunswick did state that they would try various other types of antistatic sprays to determine if one could be used.

Another approach would be to wipe the surlyn with a damp cloth or use static neutralizers (air steam of ions) or nuclear static eliminators.

It is also recommended that a test program be implemented to determine if the delay fuze line can be ignited by the trimming process.

SECTION 7
PHASE III TEST PLAN

7.1 GENERAL

This plan represents the scope of work proposed for inclusion in a "follow-on" third phase to the XM15/XM165 cluster and E8 launcher electrostatic vulnerability study. The Phase I and Phase II studies were in fulfillment of a contract which is completed with this report. Included in the work scope of Phase II is the requirement to propose a test plan for a subsequent Phase III study. This section is intended to meet that requirement.

7.2 PHASE III OBJECTIVES

The objectives of the proposed Phase III study are to:

- Conduct full scale electrostatic spark ignition tests on complete XM15/XM165 systems in a realistic simulation of field conditions and establish their spark ignition sensitivities.
- Compare and evaluate the effectiveness of modifications to decrease spark ignition sensitivity via the field simulation tests.
- Perform advanced equivalent circuit studies to include RF absorption characteristics and refined field plotting and calculating studies.
- Continue to provide technical support in evaluation of accidents involving the XM15/XM165 and E8 units.
- Perform other related studies as specified by Edgewood Arsenal personnel.

To establish these objectives, Phase III would be divided into three generic tasks:

- Field Simulation Tests
- Special Studies
- Advanced Analysis Studies

The tasks would be implemented as shown in the Phase III logic diagram, Figure 7-1.

7.3 FIELD SIMULATION TESTS

7.3.1 GENERAL

The rationale for performance of these tests is based on the requirement to know the complete system's ignition sensitivity to inadvertent (in this case, electrostatic) ignition. Subsystems of the units have been studied but in an isolated state rather than in their normal environment as a component to the complete systems. Thus for a reliable determination of the complete unit's spark ignition characteristics in various environment it is necessary to perform controlled, full-scale simulation studies.

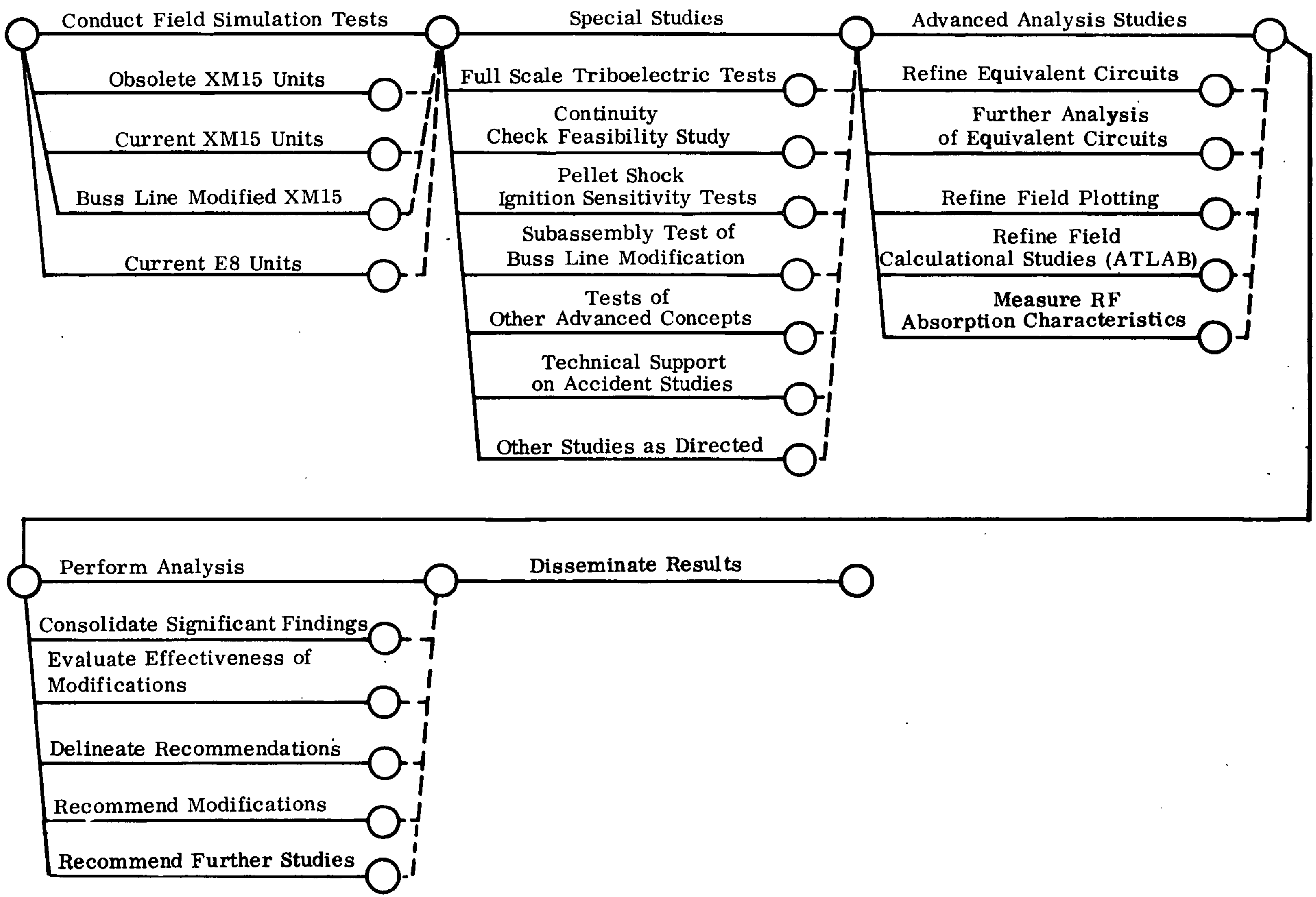


Figure 7-1. Phase III Logic Diagram

7.3.2 CONSIDERATION

The ignition sensitivity, or at least the efficiency of the electrostatic discharge phenomena, is a function of the unit's environment. In general, the unit's environment can be established upon specification of the relative humidity, the temperature (ambient and radiant heat induced, as from direct sunshine), and the coupling to ground (by direct contact as with grounded water or metal surface or by capacitive coupling). Also, the location on the unit and magnitude of energy and voltage discharged into the unit are major considerations. These conditions are specified by the experimental conditions. Another factor which must be considered is the synergistic effects of previous tests; i.e. the charge induced from previous tests may not have dissipated prior to a test, influencing the results. Such charge perseverance is most probable in regions isolated by insulating material.

7.3.3 CONFIGURATIONS

The units should be configured as for their conventional deployment. The effectiveness of the modifications currently being included during fabrication should be established by comparing to units manufactured under the original design. In addition, tests should be made of the more recent (and yet unincorporated) modifications, such as to connect all conductive components of the XM15 fuse train to a common buss line.

7.4 SPECIAL STUDIES

7.4.1 GENERAL

The following special studies are proposed as relevant studies which are related to the electrostatic vulnerability investigation.

7.4.2 FULL SCALE TRIBOELECTRIC TEST

These tests would consist of performing electrostatic potential measurements of complete XM15 and E8 units which have been in static or frictional contact with any of the materials which they would be expected to encounter during fabrication, packaging, shipping, storage and deployment. To prevent possible ignition of the units it is suggested that they be modified to replace all reactive components with inert simulants.

7.4.3 CONTINUITY CHECK FEASIBILITY STUDY

This study would consist of performing modeling (equivalent circuit) and experimental studies to determine the probability of ignition of the XM15 fuse train to end-to-end (closed loop) low voltage direct current signals. This study is related to the development of a technique to determine the conductivity (test against open circuit) of the fuse train. The resistance of the unit follows by measuring current flow and application of Ohm's Law (resistance equal voltage divided by current).

The tests would be performed on an XM15 fuse train. A very low direct current voltage will be applied to the unit for several seconds' duration.

Subsequent increasing voltages will be applied until either ignition occurs or a sufficiently high voltage is applied to satisfy requirements. Synergistic effects due to undissipated charge accumulations must be considered.

7.4.4 PELLET SHOCK IGNITION SENSITIVITY TESTS

The pellets within the junction blocks in the XM15 fuse train may be inadvertently subjected to mechanical shock during handling. The shock ignition sensitivity of the pellets in place in the junction blocks has not been determined.

Several samples would be subjected to increasing magnitudes of shock impulses until ignition is induced or test impulses exceed by an order of magnitude those expected during the most violent handling.

7.4.5 SUBASSEMBLY TEST OF BUSS LINE MODIFICATION

A thorough evaluation of the effectiveness of the buss line modification to the XM15 fuse train recommended in paragraph 5.3 is suggested. It should be subjected to the same test procedures and techniques that were employed in evaluating the effectiveness of the aluminum junction blocks and conductive cement modifications as reported in previous sections.

7.4.6 TESTS OF OTHER ADVANCED CONCEPTS

Any other modifications to reduce the electrostatic vulnerability of the XM15/XM165 and E8 units should be verified via the technique mentioned in paragraph 7.4.5.

7.4.7 TECHNICAL SUPPORT ON ACCIDENT STUDIES

Technical support should continue to be provided in investigations of accidents which may have been initiated via electrostatic phenomena.

7.4.8 OTHER STUDIES AS DIRECTED

Related studies should be performed as directed by Edgewood Arsenal personnel.

7.5 ADVANCED ANALYSIS STUDIES

7.5.1 GENERAL

These studies would be continuations of current efforts and other related studies within the unique capabilities of the General Electric Electronics Laboratory.

7.5.2 REFINE EQUIVALENT CIRCUITS

This refinement of equivalent circuits for the XM15/XM165 and E8 units should continue to be advanced. This would include all relevant measurements of component values from inert versions of these units.

7.5.3 FURTHER ANALYSIS OF EQUIVALENT CIRCUITS

Any analysis of a complex equivalent circuit is made possible by simplifying assumptions. The applicability of these assumptions is often questionable. Therefore, much effort is required to provide truly appropriate assumptions and meaningful analysis. Thus it is suggested that these efforts be continued.

7.5.4 REFINE FIELD PLOTTING

The equipotential electric field plotting capability of the General Electric Electronics Laboratory (see the Phase I Report, Paragraph 7.5.1) makes possible determination of two-dimensional fields induced by a great variety of models. The refinement of the model is contingent on understanding of the appropriate configuration. Refinements on these simulations will provide more reliable information.

7.5.5 REFINE FIELD CALCULATIONAL STUDIES

The calculation of electrostatic electric fields with the computer code ATLAB (see Phase I, paragraph 7.5.2) should also be subjected to further refinement.

7.5.6 MEASURE RF ABSORPTION CHARACTERISTICS

The General Electric Electronics Laboratory has the capability to perform precise radio frequency (RF) absorption (antenna) efficiency of these units in an existing highly refined facility. The induced signal level in the units as a function of frequency can be accurately determined.

With this information and the RF ignition sensitivity of the units, the ignition probability of the XM15/XM165 and E8 units to external RF signals can be determined.

7.6 PERFORM ANALYSIS

The various test results will be analyzed independently and collectively. Consolidation of the significant findings will permit establishment of correlations between the various tests. Of particular interest will be establishment of the effectiveness of the various modifications to the XM15 fuse train relative to the original configuration.

Recommendations would be made on procedural changes, further modifications to the XM15/XM165 and E8 unit configurations, and follow-on studies, based on the test results and the experiences gained during the program.

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